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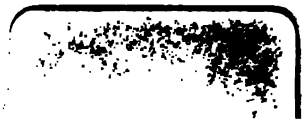

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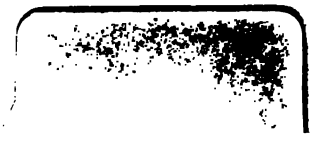

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. LXIII.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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ERRATA.

Vol. lxi., p. 378, line 11, *for* "(4·5 inches)" *read* "5·77 inches."
„ lxii., p. 367, line 14, *for* "*two* months" *read* "*ten* months."
Note.—Vol. lxi., p. 380, "Caligny's Hydraulic Exhausting Ram" has been ascertained to be based on the same principle as Mr. Michael Scott's "New Hydraulic Machine," of which a description was printed in 1847 (Inst. C.E., Tract 8vo., vol. 87).

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1880-81.—PART I.

SECT. I.—MINUTES OF PROCEEDINGS.

9 November, 1880.

WILLIAM HENRY BARLOW, F.R.S., President, in the Chair.

It was announced that the Council had recently transferred to the class of

Members.

ROBERT BURTON BUCKLEY.
AUGUSTUS JOHN DARLING CAMERON.
GEORGE LANCELOT EYLES.
ARTHUR DOUGLAS FOX.
WILLOUGHBY HANNAM.
GEORGE EBENEZER THOMAS.

Also, that they had admitted as

Students.

FRANCIS JAMES APPLEBY.
ROBERT CARY HENSLOW BARNARD.
HARDINGE BARRETT-LENNARD.
WILLIAM LEA BEARDMORE.
PHILIP HENNIKER BOSARD BEDINGFELD.
JOHN WILLIAM TOWNSEND BOYS.
SIDNEY GEORGE BROUNGER.
ROBERT WILLIAM CAMPION.
ERNEST WILLIAM CRICKMAY.
EDWARD GEORGE CRONIN.
ALFRED COOKE DREW.
HENRY SOMERVILLE FEARON.
HENRY HERBERT HELLINS.
HORACE HEY.
ANTHONY GRANT HOBSON.
ALBERT JAMES HUMBY.
REGINALD LAURENCE.
WILLIAM ANDREW LEGG.
ALGERNON LEVENTHORPE.
SIDNEY RICHARD LOWCOCK.
CHARLES LESLIE STEWART MAIS.
GEORGE CROYDON MARKS.
JOHN CHARLES MILLS.
JAMES FREDERICK MONCKTON.
CHARLES WILLIAM MORGAN.
GEORGE TAYLOR NICHOLSON.
MERVYN JAMES BUTLER PRATT, B.A.
ERNEST SAMUEL PRENTICE.
LEOPOLD SECCHI.
MALIM GEORGE SHARMAN.
EDWARD SHAW.
ALBERT EDWARD SILK.
GEORGE HUBERT THOMAS.
GEORGE WILLIAM WADE.
CHARLES BALDWIN WAKE.
FREDERIC LUMB WANKLYN.
CHARLES ASHLEY CARUS WILSON.
ALFRED YOUNGHUSBAND.

(*Paper No. 1746.*)

"Machinery for Steel-Making by the Bessemer and the Siemens Processes."

By BENJAMIN WALKER, M. Inst. C.E.

IN this Paper it is not intended to make any comparison between the Bessemer and the Siemens processes, as both are inventions for which the world must ever be grateful, and one should never be put in opposition to the other.

Much has been done to render easy the manipulation of steel in the molten state, as well as in the solid but heated state. In bringing the subject before the Institution, the endeavour will be to explain some of the appliances with which he himself has been connected. Hydraulic machinery plays a most important part in these processes, and the larger portion of the Paper will be devoted to this class of work. So extensive is the use of pressure by water, and so gigantic are the machines worked by this power, that it has become indispensable that the water employed as the vehicle of pressure should be produced and used economically. The Author has carefully considered the question, and has come to the conclusion, from actual practice, that in order to attain the former condition the boilers must be of first-class material and workmanship, and be worked at fairly high pressures, say 80 lbs. to 90 lbs. per square inch; that the most advantageous hydraulic pressure is from 600 lbs. to 750 lbs. per square inch, and that the engines for pressing the water should be compound, highly expansive, and fitted with surface condensers. Large accumulators are also necessary, and where the distances are considerable there should be several accumulators. If possible, the engines should be kept going, and not be allowed to stop and start again, as this causes great waste. This is not difficult where the machinery is extensive and the work pretty regular. The engines are much more economical when driven at from 150 to 180 feet per minute than at a lower speed, and this has been proved by frequent experiments. The valves and water-ways, especially for the inlet, should be large, the valves having but little lift. Cup-leathers and all packing which cannot be easily got at, and where leakage cannot at once be detected, should be avoided, rams being always preferable to buckets.

It is not proposed to enter into an argument as to the relative merits of compound and simple engines for pumping at high pressures, but reasons will be given why they should be compound: 1st. The expansion is put to a great extent beyond the control of the workman; 2ndly, Simple piston or slide-valves can be employed, and elaborate and complicated cut-off gear avoided; 3rdly, The cooling effect is less in the compound than in the simple engine; and 4thly, In the Author's thirty years' experience, the compound engine has always proved to be the more economical.

In his opinion, some of the strongest arguments in favour of compound engines are contained in a Paper by Mr. F. J. Bramwell, M. Inst. C.E., read before the Institution of Mechanical Engineers at Liverpool;[1] and a pair of cylinders on this system, designed by Mr. Bramwell, is the neatest and the most compact arrangement he has ever seen. The clearance between the high-pressure and the low-pressure cylinders is reduced to a minimum; and by having three separate slides, one to admit the high-pressure steam, one between the high and the low-pressure cylinders, and one from the low-pressure cylinder to the condenser, the valve-setting is exactly adjusted for each operation. The engines so designed are most economical.

Figs. 1 and 2, Plate 1, represent the elevation and plan of a pair of pumping engines of about 300 indicated HP. at the pumps. These engines are compound. The high-pressure cylinder is 30 inches in diameter, and the low-pressure cylinder is 50 inches in diameter, the stroke of each being 30 inches. To the piston-rod of each cylinder is coupled a double-acting pump, the larger ram of which is 9 inches in diameter, and the smaller $6\frac{1}{2}$ inches in diameter, or half the area of the larger. The action of the pump is similar to the ram-and-bucket pump, except that instead of a liner and cup-leathers being used ordinary packing is available. This kind of pump has been in use for several years, and has given great satisfaction; the expensive gun-metal liner is dispensed with, the construction is simple and cheap, and there is practically no leakage. The engines are fitted with a surface condenser, air-, circulating and boiler pump. The circulating pump acts as a tank pump, sending its water through the condenser tubes to the overhead tank for the supply of the feed pumps. The circular slide-bar has been adopted, as it combines lightness with strength and cheapness. It can, of course, be bored

[1] *Vide* Proceedings, 1872, p. 125.

out, which is simpler than planing, and if the crosshead is adjustable, and the wearing surfaces are large, it works remarkably well. The cylinders are steam-jacketed, and the valves and pistons, and in fact all details connected with the engines, are similar to a first-class marine engine. It is not intended that these engines should be stopped and started by the rise and fall of the accumulator, but provision is made for rendering them automatic by admitting steam direct from the boiler at a reduced pressure into the low-pressure cylinder, and by an arrangement in connection with the accumulator, shutting this off when the engines have been set in motion. Engines of this class have been found most economical, not only from the indicator cards, but from the number of boilers used in comparison with simple engines, which they have in some cases superseded, and in the consumption of coal.

About two years ago the Author's firm made for the East and West India Docks Company two pairs of compound surface-condensing pumping engines of about 150 indicated HP. at the pumps for pumping into accumulators. The boilers are of the Lancashire type, 7 feet in diameter and 26 feet long, and are capable of being worked at a pressure of 75 lbs. per square inch. The engines have two high-pressure cylinders, each 20½ inches in diameter, and two low-pressure cylinders, each 32 inches in diameter, cast together and mounted on one bed-plate, but independent. They are fitted for surface condensation. Trials have been made with these engines, and the mean result of a large number of diagrams shows a consumption of coal of 2¼ lbs. per indicated HP. per hour. The boilers are clean and free from incrustation. The large amount of water, which is very dear in London, formerly necessary to feed the boilers is now almost entirely dispensed with; only the small quantity required to make up for loss at the head box and gland of the boiler pump having to be supplied. The high-pressure engines in the same house have been made surface-condensing by a separate engine; only one-third of the boiler power formerly needed is now required, and, consequently, only one-third of the coal. During the trials these engines were maintained at a nearly uniform speed, a Harding's counter was fixed, and the coal, which was of fairly good quality, was carefully weighed, the boiler pressure was kept uniform and the feed gradual. The vacuum was 13½ lbs. per square inch. The Author has collected a large number of indicator diagrams from non-condensing pumping engines working into accumulators, and finds that the average amount of water evaporated per indicated HP. per hour is about 35 lbs.; while in some of them, with no expan-

sion, it is as high as 50 lbs. per indicated HP. per hour; whereas in the compound highly-expansive surface-condensing pumping engines only 12 lbs. per indicated HP. per hour of water were required to be evaporated.

The cost of giving to 1,000 cubic feet of water a pressure of about 700 lbs. per square inch, or, in other words, the cost of getting the same into the accumulator and pressure main, in the case of the cranes shown in the drawings (assuming that the boilers already exist), is for the ordinary high-pressure, non-condensing, non-expansive accumulator pumping engine, about 6*s.* 7*d.*, and for the economical highly-expansive surface-condensing engine about 4*s.* 3*d.* For this computation the coal is taken at 8*s.* per ton, the price paid in Leeds, next the attendant's wages, then the interest at 5 per cent. per annum on the capital expended on the engine-house, foundations, engines, boilers, accumulator and pipes, the oil, etc., and the water evaporated in the boilers in producing the steam, which in the former case is not condensed. In a large works where other power is used, and the steam required for the accumulator pumping engines is generated in the same boilers that drive the works, the above cost would be reduced. If they are well constructed at the beginning, with the wearing surfaces large, without cup leathers, and, consequently, with very little renewal, accumulator pumping engines require practically no repairs, and are in this respect more economical than any other power producers.

There seems to be no reason why accumulator pumping engines should not be as economical as any other engines. It was in pumping engines on the Cornish plan that economy first began to be considered, and some of these engines have approached perfection in the way of duty, and the Author knows no reason why the class of engines here dealt with, now so extensively used, should not be as economical. Economy must lead to more frequent use of hydraulic power. A high pressure of steam, and a high rate of expansion, independent if possible of the attendant, are necessary to ensure cheap working. Steel in its present advanced state has helped in this last-named respect, so great has been the progress made of late years. It is not only in the engine- and boiler-shop that the great advantage of steel has been found; shapes can now be rolled and manufactured of steel that formerly could not have been made in puddled iron, and no man, not having a practical knowledge of steel made by these processes sixteen to twenty years ago, can have any idea of the great improvement in its uniformity, quality, ductility and strength.

Having pressed the water to the degree required, the next question is how most economically to use it. Perhaps in no kind of hydraulic machinery has there been a greater waste of water than in the hydraulic engine, whether used for cranes or capstans. From careful experiments made during the last eighteen years, it is believed that Figs. 3 and 4, Plate 1, represent a fairly economical engine. The manner of operation will be easily understood from the figures. The two smaller rams are half the area of the larger, and are always in communication with the accumulator, the larger being brought into communication with it alternately by means of a small slide valve. The cranks being at right angles, and an hydraulic valve requiring neither lap nor lead, it occurred to the Author that the crosshead of one ram might be made to move the valve of the other. Such is the arrangement shown in Figs. 3 and 4, which represents a machine for hauling heavy weights in operation at his works in Leeds. Having made a large number of capstan engines with three cylinders, he has come to the conclusion, after careful examination and experiment, that the double-acting engine, with cranks at right angles, is as good as any, and that it has many advantages in simplicity and cheapness over the three-cylinder engine. It takes up little room, the connecting rods are long, the rams well guided, the valves and gear are simple, and the whole is readily accessible, not requiring a foundation when used as a capstan for hauling.

As a double-power engine, to exert a strain of 5 tons at about 70 feet per minute, the Author has employed a similar arrangement, but instead of a double crank, a three-throw with six rams, three and three, and with forked connecting rods. The valve for admitting the water is double-ported, and the arrangement is such that water can be admitted to either three or six rams. Engines of this class are in operation at the eastern extension of the East and West India docks for pulling the ships, and they are found to be very economical.

Figs. 5 and 6, Plate 1, illustrate a single form of ingot crane, which is very economical in the consumption of water. Most of the cranes of this type made by the Author have had the centre ram or pillar to take the weight and act as a guide, not being under pressure, the side rams doing the duty of lifting and balancing, one ram being always, and the other alternately, in communication with the accumulator. The original ingot crane was the same as shown in Figs. 5 and 6 without the side cylinders, and the centre ram had to be made large enough to lift not only the ingot, but its own weight and that of the top and jib of the crane. The two side rams

represent economy in pressure-water. The crane above alluded to not only has the water on the circular area of the centre ram, but also on the side rams, the centre ram doing the duty of balancing the dead weight, and the side rams being used either singly or together, making the crane double power. This is a great improvement over the old style of ingot crane. On the old plan, with one centre ram which acted both as guide and lifting power, there was a risk of breakage if safety and greater capacity for work were aimed at. The dead weight to be lifted was increased enormously, and consequently water was wasted. With the plan of balancing by the centre ram, which is put in constant communication with the pressure-main and accumulator, and by employing side-lifting rams, the crane may be made of any strength and power without sacrificing economy in pressure-water.

Fig. 7, Plate 1, represents an 8-ton ingot crane in operation at Messrs. Bolckow, Vaughan and Company's new steel works at Eston, where it is used in connection with the new process of making steel from Cleveland iron. This crane is extremely strong, and, unlike most cranes of this class, it is fitted with power-turning and racking-in-and-out gear. The turning is effected by a small hydraulic engine similar to that described under Figs. 3 and 4, but made to reverse. To enable this to be done, the ordinary valve is three-ported, and the admission of water to either one port or the other determines the direction in which the engine has to run. The reversing is effected instantaneously, the parts are few, and the whole is simple. The centre rams in these cranes are 18 inches in diameter, 3 inches thick, and about 30 feet long, having a stroke of 9 feet 6 inches.

Fig. 8, Plate 2, is a plan of Siemens-steel furnace, with the necessary hydraulic cranes, as in operation at the works of Messrs. John Brown and Company (Limited), Sheffield, and at the West Cumberland Iron and Steel Company's works at Workington, where this process is used for making heavy plates, bars, and forgings. There is one centre crane, similar to the centre lift used in the Bessemer pit, capable of lifting 14 tons, and which is employed in receiving the molten steel. This crane is fitted with a centre ram 18 inches in diameter, and with two side rams, each 14 inches in diameter, one being for balancing and the other for lifting the weight. The centre casting or sleeve is fitted with live rollers, and carries the jib, formed of two wrought-iron bars 3 inches thick and 24 inches deep. Gearing is provided for turning the crane round, moving the ladle on a strong carriage in and out, and tipping it. The other cranes are for lifting the

ingots, and are in all respects similar to those used in the Bessemer pit. These cranes are fitted with double rams for saving water. Over the whole pit there is a power travelling crane, worked by an engine and square shafting, capable of lifting 50 tons. The blocks and screw barrel, with common chain, are replaced by a pitch chain formed of thin steel plates and pins, and a pitch pulley of cast steel with a box for collecting the chain. The chain, formed of steel bars 3 inches in diameter and plates $\frac{1}{4}$ inch thick, is entirely machined, and is fitted accurately throughout, pains being taken that no part of it comes near the fire. All the gearing is of steel, as well as the plates and rails out of which the crane girders are formed.

The next machine to be described is the centre crane, illustrated in Figs. 9 and 10, Plate 3. This crane is large, massive, and of a somewhat novel construction. It consists of a centre ram or pillar 24 inches in diameter, and about 48 feet long, working in a cylinder with a stroke of 18 feet. It is to lift 10 tons of molten steel. The jib, with provision for a ladle at both ends, is movable on rollers, and is drawn in and out by an apparatus similar to the ordinary jigger. The crane is made to rotate by a small hydraulic capstan (Figs. 3 and 4). A ring of live rollers is introduced at the top of the ram to take the downward pressure, and a similar ring of larger rollers surrounds the ram at the part where the sleeve-casting, constructed to carry the jib, presses. The extreme range of the jib is 20 feet, but it can easily be altered, the length being about 10 feet when the metal is being poured out of the converter into the ladle, and 20 feet when the ingots are run.

Figs. 11 and 12, Plate 3, represent a 10-ton Bessemer converter, four of which were recently made by the Author's firm for Messrs. Bolckow, Vaughan and Company, to be used in connection with the process of making steel from Cleveland iron. The weight of one of these converters is about 40 tons; they are formed of wrought-iron plates 1 inch thick, riveted with 1-inch rivets with strong straps. The belt and trunnions are in two pieces, formed of cast-iron box section; the trunnions are 21 inches in diameter and 15 inches long. One belt weighs 11 tons, and is 10 feet 8 inches in internal diameter bored to fit the converter, but room is allowed for expansion. Air is introduced into the converter, according to the plan of Sir Henry Bessemer, F.R.S., M. Inst. C.E.; but the shape of the vessel is very different from the ordinary one, resembling a "Scotch haycock." As far as making goes it is simpler in this shape, and it is considered more suitable for the dephosphorization

process, where a large quantity of lime will probably be required to be blown through. The arrangement and apparatus for tipping the vessel are new. A strong and powerful double-acting hydraulic engine, similar in construction to the one shown by Figs. 3 and 4, working a steel worm and worm-wheel about 8 feet in diameter and 4½ feet pitch, is employed, and this engine can be reversed from the pulpit as in the ingot crane, by changing the direction of the water. Had a movable slide been employed, this could not have been done conveniently from the pulpit. The man in the pulpit has complete control over the vessel, which can be turned over and over and reversed at a good speed.

Figs. 13 and 14, Plate 3, illustrate a pair of vertical compound blowing engines, to be used in the process of making Bessemer steel. The steam cylinders are 42 inches and 78 inches in diameter respectively, and 60 inches stroke; the air cylinders are each 54 inches in diameter and 60 inches stroke. The high-pressure cylinder is fitted with expansion-slides on the back of the main slide, and the low-pressure with piston valves. These engines are intended to have a separate engine for condensing, but they can also be worked non-condensing. The boiler pressure is 90 lbs., and the air pressure 25 to 30 lbs. per square inch. The crank-shaft is of wrought iron 14 inches in diameter and 20 inches long in the neck; the cranks, also of wrought iron, are placed at an angle of 225°. There are piston inlet valves for the air-cylinders, and several small wrought-iron circular automatic valves for the delivery. The steam cylinders are jacketed, and there is an arrangement for admitting steam from the boiler into the low-pressure cylinder when starting the engines. The Author has compared these engines with simple engines of the same power blowing the same size of converter, and found that considerably less steam was required for the compound than for the simple engines. Mr. Martin, general manager of the Blaenavon Works, has informed the Author that when these engines are doing full work with condensation, the coal used per ton of steel is only 168 lbs. This includes the coal required for driving the hydraulic engines for moving the Bessemer apparatus. The Author believes this is the smallest quantity on record for this class of engine.

Formerly the iron used in the converter had to be very free from phosphorus, and only the ores found in Cumberland, and to a small extent in other places, were available for use in the converter. Now by the invention of Messrs. Thomas and Gilchrist, known as the dephosphorization process, aided by Mr. E. Windsor Richards, the manager for Messrs. Bolckow, Vaughan and Company,

steel can be made in the converter from Cleveland and other cheap and widely-spread ores. New energy has been given to the trade, and a cheaper and in all probability as good an article will be produced. In the dephosphorization process large quantities of metal are dealt with in the converter, and this necessitates the whole of the machinery being heavy, and to some extent complicated, rendering economy in steam and water an absolute necessity, as well as simplicity in construction and such reduction in weight as is consistent with strength and efficiency. There seems to be no limit to the production of steel, and it is the duty of the engineer to keep pace with the supply and demand by introducing simple, effective and economical appliances for its manipulation.

The machinery above described does not deal with the hammering and rolling. The Author may, however, mention his opinion that in rail rolling, the two-high mill, with compound reversing engines, is the most economical, and that in cogging it would be better to abolish wheels, increase the sizes of cylinders, jacketing them, and in fact to work direct as in roughing and finishing. It is obvious that the wheels do not make power; they cause trouble, and the sweep of the piston must be the same with or without wheels. Moreover, in the manufacture of steel plates, instead of casting small ingots and cogging with staff and tongs under the hammer, the Author would prefer large rolls and large ingots, and after cogging these ingots, to cut them into pieces, and reheat and roll them in the ordinary way.

The communication is accompanied by ten diagrams, from which the figures forming Plates 1, 2 and 3 have been reduced and engraved.

Discussion.

Mr. B. WALKER added that in order to ascertain from actual practice the value of the compound system, so far as the hydraulic pumping engine was concerned, he had taken the best example of the non-condensing engine made by Sir William Armstrong, V.-P. Inst. C.E., for Mr. Harrison, Past-President Inst. C.E., and it consumed, according to the indicator card, 35 lbs. of water per HP. per hour, while the compound engines made for the East and West India docks consumed little more than 12 lbs. Another matter to which he wished to call attention was the ingot crane. According to the ordinary way of making it, or where the lifting was done entirely by one ram, the greater the margin of safety required for carrying the load at the end of jib, the greater the diameter of the ram, and it was obvious that a larger quantity of water would be consumed at each stroke of the cranes. With the ordinary construction, where the ram was made of the diameter necessary for safety when carrying the load, the ram had much more power than was required; and if a careless workman should put more on to the crane than it was intended to carry, or if the end of the crane should come in contact with the building, or, in the case of the Bessemer works, with the converter, the crane was sure to be broken. He had known serious accidents occur from this cause. With the arrangement he had described this danger was avoided. The centre ram might have any amount of margin for safety; it might be balanced and the side rams arranged to have a maximum lift, so that the workman could not lift more than was intended, and if the jib end should come in contact with any unforeseen object no danger would arise, as the crane would simply stop. Fig. 8 showed one of the nicest arrangements he had seen. It was not altogether his own; it had been carried out in a workmanlike manner by Messrs. John Brown & Co., who were making some large ingots, and doing good work with little labour. The process of making steel, whether by the Bessemer or the Siemens method, having been invented, the success, not only in the quality but in the cost, largely depended upon the mechanical engineer. He might mention that fewer men were required in the manufacture of steel by these two processes than by refining and puddling. Figs. 11 and 12 exhibited the converters as successfully employed in Thomas and Gilchrist's process at Middlesbrough. When the Paper was written these converters had not been tried, and it was determined to

Mr. Walker.

r. Walker. work first on the hæmatite process, so that the men might become accustomed to the new machinery. The general arrangement of the pit was different from what he had before adopted; the new process was now worked very successfully. On the cranes, Figs. 9 and 10, the ladle at the end with the spout was carried to the blast furnace, or to the cupola, and brought by a suitable carriage, and put into the converter. After it had been blown, the other ladle was turned to the converter, and lowered and cast in the ordinary form of ingots, only making them very large. There was one matter in reference to the ram not unworthy of notice. In the finished length it was 48 feet; from the bottom of the pit to the top of the rising head it was 57 feet. The metal was dropped from the top, and rose this distance of 57 feet to the top—no easy task to accomplish. With regard to the blowing engine, Mr. Martin, following the ordinary practice, ordered six boilers, but found he could now work quite well with four.

r. Martin. Mr. E. P. MARTIN said it might interest the members to know that with the plant his firm had received from Mr. Walker, they had, during the past week, obtained one of the largest makes of Bessemer steel yet obtained in this country, having produced upwards of 1,700 tons of Bessemer ingots in one pit from two converters.

r. Thomas. Mr. SYDNEY GILCHRIST THOMAS could confirm the statement of Mr. Walker with reference to the converter to which he had referred. The chief peculiarity about it was that it was a symmetrical vessel, shaped something like a soda-water bottle. The symmetry had several advantages. The vessel was simple to make, and it admitted of great facility in charging, by allowing the pig to be poured into it on either side. It could be charged on one side, and teamed from the other side. Mr. Richards's desire in designing the vessel was to secure a more even wear of the lining. It was found that with the ordinary form the lining would wear more on one side than on the other, and it was hoped that by charging on one side, and teaming from the other side, the uneven wear would be obviated; and as far as the present short experience went that result would be obtained. It was at one time anticipated that the symmetrical shape would cause more metal to be ejected from the vessel than with the usual shape, in which there was a hood that threw back the projections into the vessel. It was found, however, in practice that the projections were very small, and that those that did occur fell straight back through the mouth of the vessel. The vessel was generally blown in a vertical position, so that any projections fell back directly into it. The

form was one that would be probably largely adopted in future; at all events it possessed decided advantages, the importance of which would no doubt be more fully appreciated after a longer experience. A considerable number of Bessemer plants were now being erected on the continent, and the compound system was generally preferred for the blowing engines. The compound engines already built had proved highly successful in regard to economy of fuel, and he thought there was a probability of the system being largely adopted for Bessemer blowing engines, at least on the continent, where economy of fuel was of greater importance than in this country. Experience, he thought, had confirmed the Author's anticipation that economy in the Bessemer process, and also in the Siemens process, would in future be best served by powerful machinery, so as to produce large makes from a single plant. In that way great economy of labour would be obtained, and also important savings in regard to all other items of expense. Mr. Thomas

Mr. E. B. ELLINGTON thought the Paper would have been more useful if it had contained more of the data from which the deductions had been made. He agreed with the Author as to the advantage of using a pressure of about 700 lbs. per square inch; a pressure first adopted by Sir William Armstrong as a standard, and which experience had shown was practically the best; though for some purposes lower and for others higher pressures were better. The Author thought it an advantage in hydraulic pumping engines that they should not stop, but go on continuously. For himself he had always considered it preferable, and a great economy, that hydraulic engines should stop when there was no work for them to do. He could quite understand that the Author might be in some difficulty in the arrangement of the compound engines he had adopted. He had stated that there was a special plan by which they could be started automatically, but that they were not made for that purpose; and he gathered that the apparatus was not intended to be used. Perhaps the Author would mention the pressure that had been adopted for the Bessemer plant to which he alluded; whether it was the 700 lbs. which he considered the most economical, or the more usual 350 or 400 lbs. It was stated in the Paper that the hydraulic pumping engines consumed about 2¼ lbs. of coal per indicated HP. per hour. That was what might be expected, and it was a reasonably good result with the class of engine used; but the point which it was more particularly desirable to know was the duty derived from the engines. The indicated HP. of course gave a knowledge of the engine to Mr. Ellington

Ellington. a certain extent; but in a pumping engine like that described, the quantity of water delivered by it was the great feature showing whether it was economical or not. Again, he was in the dark as to what was intended to be conveyed by the comparison of lbs. of water evaporated per indicated HP. For such a comparison to be of service, something of the different styles of engines should be known, the kind of boiler used, and the like. He could not understand the statement of the evaporation of 12 lbs. of water per indicated HP. per hour; the coal consumption was said to be 2¼ lbs., and that would give about 5 lbs. of water evaporated per lb. of coal. He had had some experience in regard to the actual cost of pumping water in connection with the Public Hydraulic Power at Hull, and he agreed generally with the Author's statement, giving the cost at 6*s.* 7*d.* per 1,000 cubic feet; but he thought that could not include all the items—rates and taxes, for instance. If all the expenses were included he thought the figure would have to be raised to about 8*s.*, and for the highly-expansive surface-condensing engine to about 6*s.* 6*d.* He partly endorsed the Author's views as to compound engines, and he believed they were being generally adopted where a large amount of work had to be done. In Hull new pumping engines had been recently put down on a somewhat similar system. He presumed that the Author intended to compare the capstan engine shown in Figs. 3 and 4 with the three-cylinder engine which he had formerly used, and not with Mr. Brotherhood's three-cylinder hydraulic engine, which he believed was unrivalled as an hydraulic engine. It had by far the fewest parts, and required the least attention. The engine was practically the same as the one generally adopted by Sir William Armstrong; the only difference was that there were four cylinders instead of two. Four rams were used instead of two rams and pistons, and the valve arrangements were more complicated. With regard to the crane (Figs. 5 and 6), he had not had much personal experience in the matter; but if he understood the diagrams correctly the centre ram in that crane was not an hydraulic ram at all, but a steadying ram; it passed through the lower part of the cylinder, and was really double the stroke of the lift. It occurred to him that if the upper part of the ram were made of a somewhat larger diameter than the lower, and if an internal balancing ram were introduced, the two cylinders which now formed the lift might be dispensed with, and the same effect would be produced. In explanation of the [redacted]ing remarks to the three-cylinder hydraulic engine, he [redacted]d to some drawings of Mr. Brotherhood's three-cylinder

engine and capstan, and also of a three-cylinder vertical compound pumping-engine, which he considered would give better results than the usual type of compound engine described by the Author. He also exhibited a diagram (see page 36), the relative velocity curves of suction and discharge in two double-acting bucket and plunger pumps set at right angles, and in a three-throw pump, showing a much more even and regular flow of water in the case of the three-cylinder pump and engine. Mr. Ellingt

Mr. J. G. MAIR remarked that the quantity of water used per indicated HP., as measured from the diagrams, was most fallacious, because in some instances the initial condensation on admission was as much as 50 or 60 per cent., and in others as low as 10 per cent., and where superheated steam was used it was lower still. Therefore, unless the quantity of water pumped into the boilers was known, the weights as taken from the indicator diagrams were most deceptive. With reference to the statement as to 12 lbs. of water being used per indicated HP. per hour, he might mention that the smallest amount of water that he had known used in a fair and reliable trial was about 7 kilogrammes, or 15½ lbs. That result had been obtained in France by Mr. Hirn, with superheated steam at 215° Centigrade. The bare statement of the quantity of water used by different engines would not give an absolutely fair comparison, because the amount of heat necessary to generate 1 lb. of steam varied with the pressure. It would be better, in testing engines, to measure the heat that passed through them, and to give the number of thermal units used, which was the only accurate comparison. From trials made with engines, he thought the best result the Author could give would be about 18 or 20 lbs. In the Paper, great stress had been laid on the clearance between the high-pressure and the low-pressure cylinders being reduced to a minimum, but it had been proved that there was really nothing in that. In the system adopted by Mr. Cowper, M. Inst. C.E., a large steam-jacketed reservoir was placed between the high- and the low-pressure cylinders, through which the steam passed and was re-heated, an arrangement which in practice was found very economical. He agreed with Mr. Ellington as to the amount of 2¼ lbs. of coal consumed. If that were right, it was a very large quantity. From several trials he had found that he could do with about 1·7 lb. As early as 1853 engines had been designed by Dr. Pole, M. Inst. C.E., for the Lambeth and Chelsea waterworks, and similar engines were tried in 1867 by Mr. Hawksley, Past-President, Inst. C.E., in which only 1·61 lb. of coal per indicated HP. per hour was used. Full particulars of Mr. Mair.

Mr. Mair. these engines would be found in the Minutes of Proceedings of the Institution.[1]

Mr. Rich. Mr. W. E. RICH agreed with Mr. Mair that if the weight of steam used per indicated HP. per hour was determined from measurement of diagrams, the result must certainly be fallacious. The only fair way to determine such figures was to measure the feed-water delivered into the boilers, and take indicator diagrams and the revolutions shown on a counter frequently during a trial of several hours' duration. The greatest degree of economy he had arrived at on such a ten hours' trial with compound beam pumping engines, fitted with every provision for economy, was 16·8 lbs. weight of steam through the cylinders, and 2·9 lbs. through the jackets, making in all 19·7 lbs. weight of steam passing into the engines per indicated HP. per hour. Considering the difficulty with which those results were obtained, he thought it impossible that the horizontal engines described in the Paper could work with only 12 lbs.

Mr. Tweddell. Mr. R. H. TWEDDELL said the members were much indebted to the Author for laying before them his practice in regard to this application of hydraulic power; but although he had told them a great deal, he had left a great deal untold. The chief feature of his practice appeared to be the use of rotary engines, and those of a very questionable type, in every possible situation, and in some cases where, in Mr. Tweddell's opinion, a direct-acting ram would have been better and simpler. No doubt the Author had good reasons for departing from the older practice, and it would have been interesting to have been told what those reasons were. According to his experience the rotary engine described by the Author was not so advantageous an application as Sir William Armstrong's direct-acting ram, where the latter was practicable. As to the engines shown by Figs. 11 and 12, he was not aware whether there was any advantage in them, or any necessity for adopting them. It was stated in the Paper that "the man in the pulpit has complete control over the vessel, which can be turned over and over and reversed at a good speed." Of course it was interesting to know that such an affair could be "turned over and over," but unless there was an absolute advantage in so doing, it appeared hardly sufficient to justify all the gearing involved in using one of the Author's class of engine. In a Paper by a great authority in America, Mr. A. L. Holley, M. Inst. C.E., it was stated that "the output of a pair of converters in Europe

[1] *Vide* vol. xxiii., p. 45, *et seq.*

averages about half that of a pair of converters of the same size in the United States."[1] He asked why this should be so? and alleged that this was excused on the ground that quality would be sacrificed to attain greater speed; but as Mr. Holley truly remarked, he could not see why the steel should be better because two hours were consumed in setting a converter bottom instead of one. Now the Author had given no information on this head. He believed that a good deal of attention was being paid in America to the application of hydraulic power for repairing the converter, and it appeared probable that there would be more changing and repairing under the basic process than had been previously required. The statement in the Paper that from 600 to 750 lbs. per square inch was the best pressure for this class of work, confirmed as it had been by the practical experience of Mr. Ellington, was interesting; but he should be glad to learn why that pressure was better than 1,000 or 1,500 lbs. The only possible objection was that of getting the rams and other parts too small for connecting them with the gearing, but in most cases that might be overcome. With regard to the capstan engine alluded to so often in the Paper, he could not see any difference in the design from that used by Sir William Armstrong. There was certainly a connecting-rod in addition, and other complications, but these were doubtful improvements. He supposed that there must be some good reasons for preferring an arrangement necessitating three-slide valves, and a corresponding number of connecting-rods when the work might all be done as in Mr. Brotherhood's three-cylinder engines, with one valve and with no connecting-rods. He should like to ask if the Author had experienced any trouble from frost in connection with hydraulic pressure, and what was, in his opinion, the best mode of meeting a difficulty felt by all who were engaged in supplying hydraulic power. With regard to the apparatus shown in Figs. 9 and 10, he should like to have a little more information as to how the jib was moved in and out on the top of the ram. There would appear to be a moving weight of from 20 to 30 tons, but there was no description as to how the jib was traversed. Mr. Tweddel

Mr. E. A. Cowper thought the Author had given some of the best examples of engines and pumps. As to the question of pressure for Mr. Cowper.

[1] *Vide* "An adaptation of Bessemer plant to the basic process. A Paper read before the American Society of Mechanical Engineers at the New York meeting, November 1880." Inst. C.E. Tract 8vo. See also "Engineering," vol. xxx., p. 403.

Cowper. working hydraulic machinery, it might, according to circumstances, be 600 lbs. or 700 lbs. per square inch, and in some cases it might be convenient to make a small cylinder run to 800 or 900 lbs. As a matter of practice it was not very important whether the pressure was a little higher or a little lower. When he first used an hydraulic reservoir for forging iron he called it a reservoir, the term "accumulator" not then having been invented. He had merely adopted an hydraulic reservoir which he had seen in use at a paper mill where there were a number of hydraulic presses, and one amongst the number was heavily weighted to work the others. In forging iron in large quantities he found that an hydraulic reservoir was very handy to keep up a constant pressure, and give quick action. It was afterwards used by Sir William Armstrong for working hydraulic machinery generally. It was scarcely worth while to stop pumping engines for an accumulator or reservoir, because when there was a large amount of work, they were required to be kept going, and a variation in the work, taking the average of a large number of machines, merely amounted to a variation in the speed of the engine. The engine went a little faster or slower; sometimes, perhaps, it was a little fast, but there was no necessity to stop it where constant work was done in large ironworks. The automatic machinery of Sir William Armstrong for regulating the velocity of the engine was, however, very pretty, and answered its purpose well, where there was a great variation in the work to be done. It might sometimes be advantageous to let it stand for half an hour, but in large ironworks where an accumulator was constantly wanted, it was not necessary to stop the engine. If a little water was allowed to run to waste, it was not of much consequence, but as a rule there was no waste. With regard to cup-leathers, he agreed that it was preferable to do away with them inside cylinders, if possible, and to work with stuffing-boxes with or without cup-leathers outside, as they could be got at. There was an excellent form of pump indicated in Plate 1, Figs. 1 and 2. The Author stated that the action was similar to that of the "ram and bucket pump," and certainly the advantage of putting the valve outside instead of in the bucket was very great, and the two plungers of different sizes did away with the necessity of packing a bucket. He believed the plan of placing the valve outside was adopted by Sir William Armstrong at the suggestion of one of his foremen. He agreed with the Author's reasons for using compound engines, but there were others that had not been mentioned. One was, that the rotative power was more regular, and the strains

were therefore much less. If the actual rotative power were set out on a diagram, it would be found that it was very regular indeed, if the cranks were at right angles and the steam was cut off at half stroke. Therefore the variation in pressure due to expansion was very advantageous. There was an expansion in the high-pressure cylinder, and another in the low-pressure, and in the multiple of the two there was great economy. The question of the Cornish engine was somewhat different, because in the Cornish engine there was the advantage of a large weight to be put in motion; there was the *vis inertiæ* of that weight by which steam could be applied at high pressure in a single cylinder; the weight was got up to a high speed, and the momentum of the weight finished the stroke of the pump. Unless there was a heavy weight to pull at, it was impossible to work an engine on the Cornish principle; therefore it was convenient in the engines under consideration to divide the expansion into two cylinders, with cranks at right angles. He had many years ago attempted to get great economy in one cylinder, expanding ten or eleven times, but the rotative power was not regular, and he came to the conclusion that compound engines with cranks at right angles would be far the best. A statement was made in the Paper that "The high-pressure engines in the same house have been made surface-condensing by a separate engine." That meant, he supposed, a condenser and a separate small engine to drive the air-pump, not that the engine condensed the steam. Two or three more words would have made the matter clearer. At present it was not quite clear how with that construction of engine only such water should be used as had leaked away in the stuffing-box. He presumed the fact to be, that it was a pumping engine, and that the water that was pumped was used first for condensation. That was now being done in many waterworks. He had introduced it in the Lambeth Waterworks under the late Mr. James Simpson, Past-President Inst. C.E., many years ago. That the coal might then amount to only one-third in a compound engine was most undoubted, he would even say one-fourth. He had known the amount to be as low as 1·3 lb. of coal per HP. per hour, and that meant less than a fourth of a cubic foot of water, or a third of the coal. A comparison had been made in the Paper with non-condensing pumping engines, and the examples were taken from Sir William Armstrong's practice. It was of no use comparing non-condensing engines with highly expansive condensing engines, working with high pressure in the boiler. Of course in the latter case, it was possible to work with much less water and coal than in the other case. All

Mr. Cowper

rper. compound engines with surface condensers were good for pumping for hydraulic accumulators; no argument was required to prove it.

The Author had referred to the great facility with which steel could now be made into almost any shape. He quite agreed with that remark, and he hoped there would be still greater advances in that direction. The material was so good, that it might be forced into shapes never dreamed of with wrought iron years ago. He agreed with the Author that it was the duty of the engineer to keep pace with the demand. He had spoken on the subject before, and he hoped that more attention would be given by engineers to some of those specialties. They had an admirable material, without any special weakness in one direction like wrought iron, and they ought to treat it in the best manner, and make the most of it. With reference to the capstan engine the Author stated, "The two smaller rams are half the area of the larger, and are always in communication with the accumulator." It appeared to him to be a very neat and simple arrangement. Of course it was open to the objection that there were four cylinders instead of two, but there were only two rams. The two smaller rams were constantly under pressure, and were overcome by the large ends of the rams being twice the area; so that in pushing with a force of 2 there was a force of $2 - 1 = 1$, and there was a pressure of 1 to come back with. There was an equal pressure in each direction. With water the cylinder was filled at every stroke, whether the water was used at the full pressure at which it had been pumped or not. There was no objection whatever in using one ram against the other so far as he could see; there was no loss of water, or of power, further than the slight friction of the small ram. With regard to the arrangement for tipping the converter in the Bessemer process, something had been facetiously said about turning it over and over. The large worm-wheel and worm was an efficient mode of turning the converter, and he was well aware that when it was made of the vertical form, it was very useful to be able to pour from it on either side as in working the Thomas-Gilchrist process. So far as he could see, he thought it an improvement on the old rack and pinion. He did not quite understand what the Author meant by the statement that "a large quantity of lime will probably be required to be blown through," and perhaps he would give some explanation on that point. The heavy machinery used in the dephosphorization process, no doubt, required heavier engines to work it, and it appeared that that had been thoroughly met by the improved machinery which

the Author had introduced. The vertical converters and their machinery at the Cleveland Steel Works, under Mr. E. Windsor Richards, were really a grand sight. The man in the "pulpit" had complete control over them, having merely to open and shut the valves. With reference to cogging, he did not quite agree with the Author, because he thought that if the rolls were direct upon the engine-shaft, one would naturally have a higher speed than was advisable, and larger steam cylinders would be required, as the steel should be given a little time to swell out longitudinally. In other respects he agreed generally with the statements made by the Author, and thought he had certainly improved the machinery required for working steel. Mr. Cowper.

Mr. F. J. BRAMWELL observed that the discussion had turned upon the quantity of water used per indicated HP. He had no doubt that the Author, in his reply, would say he did not intend the Institution to understand that the water actually used by his engines was only 12 lbs. per indicated HP., but that by comparing one diagram with another, and taking the quantity of water used as calculated from the diagrams alone, the proportions were as he had stated. Of course, as had been pointed out, this mode of calculation was open to the objection that in one kind of engine there might be more initial condensation than in another, and that therefore such a mode of calculation was not to be relied on even when used only for purposes of comparison. While upon this subject, it might be interesting to the members to have recalled to them the actual consumption of water as brought out at the trials in 1872, at Cardiff,[1] with portable engines, absolutely without condensation, and working at only 80 lbs. per square inch. The most economical consumption there was 24½ lbs. of water per gross indicated HP. per hour. Looking at that fact in connection with the non-condensing engine, he hoped it was not unreasonable to expect that in time, at all events, condensing engines would be made which would consume actually as little water as the 12 lbs. suggested by the Author, but not suggested, he believed, as the actual total consumption. Mr. Bramwel

Mr. W. SCHÖNHEYDER could not quite understand what was said with reference to Fig. 2, but he believed it related to a gland between the small plunger and the large plunger to stop leakage, instead of employing a packed piston. It was a neat arrangement, Mr. Schönheyder.

[1] *Vide* The Journal of the Royal Agricultural Society of England. Second Series. Vol. ix., Table II., p. 61.

but he did not quite understand from the drawing how it was possible to see the leakage, though it would be very convenient to be able to stop leakage when it was known to take place. He saw an engine some time ago of that identical construction. He guessed what was the object of the gland, and he asked the driver about it, but he did not know what it was. He asked him if he tightened it up, and he replied, "Very seldom; I do sometimes." It then occurred to him that although it was convenient to have a gland for tightening the plunger, no means existed for ascertaining when the leak occurred. He should like to ask whether the Author, in his large steam engines, universally adopted the plan of casting the jackets with the cylinders. He imagined, from Fig. 13, that the jackets were cast in one with the cylinder, and apparently it was a very large cylinder. The wise plan had been adopted of making the jacket portion in two lengths. It was made much more tight and solid by being cast together, though there were risks attending that method.

Dr. C. WILLIAM SIEMENS said the Author had wisely confined himself to the manipulation of steel after it had been produced. If he had attempted to deal with processes, his Paper would have assumed dimensions far beyond the scope of what could be dealt with at one time, and there would also have been chemical considerations involved which would have led beyond the usual range of the discussions. He had, however, mentioned two processes now largely used: the Bessemer process, which, by the great revolutions it had effected not only in the manufacture of iron and steel, but in the engineering of the world, was too well known to require any further comment; and the process with which Dr. Siemens' name was connected, which, although much less used, had been in existence nearly as long as the Bessemer process; and which, although it had been for many years confined to comparatively few works, had lately, owing to some particular advantages it possessed under certain circumstances, attained a considerable extension. Setting aside the question of process, the Paper dealt very ably with the modes by which the ingot metal should be treated in order to convert it into such forms as were required. The Author advocated economy in the construction of the steam-engine, a subject which Dr. Siemens was glad to see had been taken up at last seriously by the makers of that class of machinery. At the time when the puddling furnace and the reheating furnace sent up flames of living fire into the air, the question of economy in the engine was really a superfluous one; there was so much steam produced in using only a portion of

the heat that would otherwise have been entirely thrown away, that the difficulty rather was how to keep it under, than to economise it. The converter, however, and the regenerative gas furnace had materially changed that condition of things. The heat was now in a great measure utilized to do its work; it was employed for producing the effect required, and there was little heat to be thrown away. If, therefore, steam was required to work the metal after it was produced, that steam had to be raised by means of special fires, and it became as important to work mill-machinery upon economical principles as it was a steam-engine on board ship. No wonder, then, that economical engines had attracted the attention of those practically engaged in working steel; and he quite agreed with the Author in selecting a compound engine as the type which was perhaps the most suitable for the purpose. It distributed the load very uniformly upon the crank centre, and it carried out the system of expansion without involving a maximum strain too much above the mean strain on the working piston. The Author proceeded to recommend a form of engine working directly on the roll, and in that respect he was obliged to differ from him. It was stated that in working the steam cylinder with the connecting-rod directly upon the axis of the roll, gearing was saved. That was true, but the gearing was saved at the expense of an enormous strain on the crank pin, an elaborate foundation, and a relatively slow working of the piston. Admitting the advantage of simplicity in connecting an engine directly to the working crank, there were the drawbacks to which he had referred, which were in fact drawbacks in regard to economical results, and also in regard to the first cost of the engine. If the gearing was properly constructed, and if the wheels and pinion were made of steel, there was, in his opinion, nothing very objectionable in it. A quick-working engine was more economical and more easily repaired than a slow-working, long-stroke engine, and the pinion and wheel were convenient pieces of mechanism to convert the speed into the degree of reduction necessary to work a pair of rolls: he therefore thought it would be better, on the whole, to continue the system of having a quick-working reversing engine, and to reduce the circular velocity by gearing. The Author had also dealt with the question of hydraulic arrangements for working the pit both with the Bessemer converter and with the open-hearth furnace, and in other parts of the machinery; and the question arose, what pressure would be most suitable for such a purpose? Sir William Armstrong was quoted as an

Dr. William Siemens.

William authority for fixing 700 lbs. to the square inch as the proper
ns. pressure to be used; and for such purposes as had been named he believed it was a very convenient working pressure. It would, however, be wrong to assume that Sir William Armstrong advocated that limited pressure under all circumstances. Dr. Siemens went to him last year and asked whether he could make a cylinder hydraulic ram of 3 feet diameter to work to 8,000 lbs. pressure per square inch. He was rather struck by the proposition, but he did not say "No." Although his first idea was to use a coil for the cylinder to give strength to it, a forged steel cylinder of 7-inch wall thickness was eventually decided on. The accumulator and other hydraulic arrangements were carried out by Sir William Armstrong, but the hydraulic cylinder was furnished by Sir Joseph Whitworth of compressed steel. He mentioned this case to show that there was almost no limit to the hydraulic pressure that could be called into requisition. The special object he had in view was to place telegraph cables under the equivalent of Atlantic pressure. Into the plungers cores of insulated wire were placed, and a pressure equal to the deep-sea Atlantic pressure was applied. It was of great value for such a purpose, inasmuch as it ensured the soundness of the insulating covering when it came to be subjected to the enormous pressure which it had afterwards to bear. But he thought that hydraulic arrangements of equal force would be applicable with great advantage for metallurgical purposes in pressing rather than beating steel into its definite form.

Kennedy. Professor A. B. W. KENNEDY remarked that the Author had spoken first about pumping engines and hydraulic gear. The primary qualification for machines of this kind was that they should do directly the precise thing they were wanted to do. Of course, any notion of that kind might be carried too far; at the same time one liked to see the principle of direct action carried out as far as possible, and it was wonderfully possible in the case of hydraulic gear. In pumping engines it would be well that engineers should remember that the fly-wheel, the connecting-rod, the guides and so forth, were not, under ordinary circumstances, required for the actual process of pumping. The pumping was a direct reciprocating motion, and the steam piston had itself exactly this motion already. The added motions might or might not be necessary as auxiliaries, but they were at any rate not necessary to the main purpose in hand. The compound engine had the advantage, among others, that the driving moment on the shaft could be so equalized that the fly-wheel might be reduced to

comparatively small dimensions. He thought that in many cases engineers had not realised this; or perhaps they did not agree with him in thinking that the fly-wheel was not wanted; but he felt sure that in many cases, in well designed compound engines, the fly-wheel, &c., might be made much lighter, and the change would effect a great saving in first cost, as well as an economy in working. As to hydraulic work, he was glad to see amongst the drawings an arrangement of a crane which was to have a self-acting racking in-and-out gear, and also self-acting turning gear. One could not help being struck, in connection with the Bessemer plant and work, with seeing how much was still left to the hand when so much was done by machinery. Of course the rotating of the crane was a rotary motion that might be fairly expected to be got by a rotative engine. The Author did not say how the racking in and out was got. Would not the simplest way of obtaining this motion be by the use of an hydraulic cylinder placed upon the crane arm and acting directly upon the truck? The cylinder and ram would be utilized as a counter-weight. It would a little lengthen the counter-half of the crane, but not to any great extent. He hoped the Author would say how it was done. There was one observation in the Paper which he did not quite understand. The Author said:—"Having pressed the water to the degree required, the next question is how most economically to use it," and then proceeded to describe his little hydraulic engine. He did not see that the engine in question, any more than other direct-acting hydraulic engines, could obtain economy of water. At a discussion not long ago upon a Paper by Sir William Armstrong,[1] it seemed to be pretty generally held that in the majority of cases it was not worth while to attempt economizing water, at least by any of the systems proposed so far. Be this as it might it was a little misleading to speak of any of the engines described being economical of water except so far as the workmanship was good, the stuffing-box tight, and so on. They used pressure water throughout the whole of their strokes. One or two ingenious arrangements which appeared to have elements of success in them had been proposed for allowing non-pressure water to enter the cylinder at a certain point in the stroke, so as to work the water, as it was called, expansively. He did not know, however, to what extent they had been carried out successfully in practice. It appeared to be the simplest plan for economizing water, but he imagined that, after all, economy of water did not come much

Prof. Kenn

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. l., p. 64.

Kennedy. into account in Bessemer works. He should be glad if the Author would state his reasons for having a rotative engine for moving the converter. It was impossible to suppose that the Author, and such an eminent ironmaster as Mr. Windsor Richards would adopt that method without good reasons, but at first sight it appeared to have certain drawbacks. The ordinary rack-and-pinion and direct-acting ram would turn the converter right over, although it would not turn it round and round; but as he understood the matter, it was not necessary that the converter should be turned round and round. He had understood from Mr. Windsor Richards that the chief reason for adopting the straight nozzle was the trouble that had been experienced in gagging up at the bend. The mixture of lime and iron which had accumulated there had been very troublesome; and it was expected by making the mouth somewhat large and straight out to get rid of that trouble. One point that he hoped would be mentioned in the course of the discussion was the general disposition of the converter in Bessemer plant. There were two distinct types of Bessemer plant in this country, of which the Author had shown the least common, namely, the American type of plant used at Eston. In this the converters were put high above the ground; there was no pit, but the ingots were cast on the ground level. The ordinary plan in this country was to cast the ingots in a pit, and arrange the converters facing one another instead of side by side. To an outsider like himself the superiority of the Eston plan appeared to be very great. It was possible to get under the converter for repairs and for changing bottoms; and it was not necessary to lift the ingots 7 or 8 feet before putting them on trucks. Time was saved just when it was of most importance, when the ingot was being lifted, and the process was much simpler and much less trying to the men engaged in it. The advantage of Mr. Holley's method of changing the converter bottoms, he supposed, went far to account for the enormous production of some of the American Bessemer plants as compared with most of those in this country. Mr. Tweddell had alluded to a plan advocated by Mr. Holley for changing the converters with the basic process. He understood that at Eston the converters were to be lifted bodily out of their trunnions and removed by a 60-ton travelling crane. Mr. Holley had proposed to drop the converters down inside their trunnion rings on to a truck having an hydraulic ram, and remove them in this fashion. The new converter was to be pushed up into its place in the trunnion ring by a similar ram. This plan, he understood, was about to be carried

out in France, at or near St. Etienne, and no doubt when the basic process was worked in America, Mr. Holley's plan would be adopted there. To an outsider it certainly seemed to possess great advantages, although, no doubt, the inventor had somewhat exaggerated the difficulties experienced in lifting the converters out of their trunnions. In any case, it was satisfactory to observe that there were engineers willing to take in hand a new process of this kind, and to prepare deliberately, and apparently as a matter of course, for encountering and overcoming such enormous practical difficulties as were involved in the frequent bodily removal and renewal of converters of this magnitude. Prof. Kent

Mr. JOHN FERNIE wished to make a few remarks on the reversing rail rolling mill recommended by the Author. In the last volume of the 'Minutes of Proceedings' there was a description of a rail mill at Seraing, giving the theoretical quantity of steam used in a reversing rolling mill.[1] The ingots were passed backwards and forwards, the engine reversing every time. According to the Paper two different rolling mills were employed, one for cogging down, and one for roughing and finishing, and there were twenty-four different passes that a steel rail had to go through before it was turned out as finished. It was stated that there was an average of a cylinder and a half of steam wasted every time that the engine went backwards and forwards, and it was calculated that on each rail 107·36 lbs. of steam were wasted. Multiplying by the number of rails rolled, there would be about 2,147·2 lbs. of steam wasted per hour in the reversing rolling mill. The steam per hour used in the two engines for continuously rolling rails was 27,480 lbs. To ascertain the boiler power required for such work, it was necessary to take a square foot of boiler surface as being able to evaporate 3·7 lbs. of steam per hour, and in that way there appeared to be a heating surface required of 7,430 feet. Taking the quantity of steam lost in the reversing process, the amount of heating surface was 580 square feet. The rails made at Seraing were rolled from 15-cwt. ingots in double lengths. At Crewe rails were rolled in single lengths, and the ingot had to pass through the rolls seventeen times to finish it into a rail; and had each single rail at Seraing to pass through a reversing mill seventeen times instead of twelve times the loss in steam would be equal to 821 square feet of surface, nearly a boiler power. By putting another roll on the top of the two-roll mill, and bringing the ingot first through the lower Mr. Fernie

[1] *Vide* vol. lxii., p. 411.

'ernie. pair, and carrying it by a movable platform worked by hydraulic pressure up to a sufficient height to pass through the upper pair, and again lowering it to pass through the lower pair, and so on, a continuous motion of the mill and the rail was maintained and no reversing apparatus was necessary, and this he believed would be the rail mill of the future. At Crewe, where the reversing mill was invented, a rail mill on the principle here referred to had been erected. He need not say that there must be an immense saving in that mode of rolling a rail; the motion was direct, there was no stopping and starting the engines. The only power that could be lost was during the short interval of time between the rail passing from the one groove to the other, but this power was absorbed by the fly-wheel, and came out again in useful work. At Seraing the first engine which drove the cogging reversing mill had two cylinders 32 inches in diameter and 4 feet stroke, and the roughing and finishing mill was driven by a double cylinder engine of which each cylinder was $39\frac{3}{8}$ inches in diameter and 4 feet stroke, and these two mills turned out 32 feet of rail every ninety seconds. The rail mill at Crewe was driven by a single cylinder engine 40 inches in diameter and 5 feet stroke, and turned out a rail every eighty seconds. He had lately seen an account of a similar mill to the Crewe mill, which he had visited at Bethlehem in Pennsylvania, and which had turned out a rail in fifty-six seconds. Thus the work of the three mills was for ten hours:—Seraing, 400 rails = 136 tons; Crewe, 450 rails = 170 tons; Bethlehem, 633 rails.

A great deal had been said about compound engines, and he quite believed that for many things they were very desirable. For spinning thread and purposes of that kind nothing could beat them in economy and in steadiness of motion; but for rolling rails or heavy iron a slow engine of slow circulation was not wanted, but one that was lively and active when work was thrown upon it. Take a line A B, divide it into 12 parts, and call the whole length one minute, then each of the divisions represented the passage of a rail through the rolls. Draw a line parallel to this, and call this the power required to drive the engine with its fly-wheel, say 50 HP., then by drawing lines in proportion to this and corresponding to the power required, an idea would be obtained of the variations which might occur in a minute in rolling steel rails in the Crewe mill. So suddenly and rapidly did these changes occur that they might be described as blows, and indeed at the first contact and until the pressure of the rolls had compelled the crystals of the steel to flow they might be

called blows. From diagrams of the Crewe engine[1] it appeared that these variations in the power given out reached from 220 HP. to 670 HP. It would thus be seen that for this kind of work a very lively engine was required. The engine best calculated to meet these variations of time and of power consequent on rail rolling was the Corliss engine. No other engine admitted its steam more rapidly and just when it was required, and no engine wasted so little steam and had so little friction in its valves. At Crewe, where a magnificent Corliss engine drove the rail mill, the whole arrangement of engine and mill might be called the American principle of rail rolling as in opposition to the reversing mill. Mr. Fernie

Reference had been made to the reversing plate mill. While there was much more reason for the adoption of such a mill for rolling plates than for rolling rails, yet he would greatly prefer a single cylinder engine working direct on the rolls without gearing, the rolls however to be reversed by means of gearing, for reversing was a necessity for roughing down plates.

Adverse comment had been made on the Author's way of turning round the converter; but he thought that in that kind of work a man ought to be allowed to decide which way was the best. If the Author could have shown more steel in connection with the machinery he had described, it would have been very encouraging. It was true he had given examples of pinions, wheels, links, and so on, but he should like to hear that the cranks, the girders and the boilers were made of steel also. He should also have been glad if the Paper had given some idea as to the Author's experience in the working of steel. So far not so much had been done at Leeds in that way as at Manchester. Nevertheless, one of the best Papers on the application of steel for boilers had lately been produced by Mr. Greig and Mr. Max Eyth of Leeds,[2] a Paper which contained a record of many beautiful experiments, and which would, he thought, prove of great use to those who were engaged in steel working. He could state from personal knowledge that the Author had done a great deal of work, and done it in a first-rate manner.

Mr. BRAMWELL said Mr. Fernie had referred to a recent volume of the Minutes of Proceedings containing an abstract of a Paper, from which it appeared that a Belgian engineer was of opinion that by employing steam to reverse an engine, steam was con- Mr. Bram

[1] *Vide Engineering*, vol. xxii., p. 359.

[2] *Vide* Institution of Mechanical Engineers. Proceedings, 1869, p. 268.

Bramwell. sumed in the employment. He was not able to follow that train of reasoning. In the Le Chatelier brake, for instance, the "Contre Vapeur," steam was employed to arrest the motion of the engine; but, so far as he was aware, there was no consumption of steam; on the contrary, there was a conversion of the energy into heat. The water put into the cylinder for the purpose of preventing the scoring of the cylinder was converted into steam and pumped back into the boiler. An engine was running in one direction; it was put into the backward gear, steam was introduced, and it was sent back into the boiler, not wasted. The cylinder was filled with steam, and the steam was returned into the boiler. As to whether it was better to reverse or whether the expense of three-high rolls with rising platforms should be incurred, so that the rolls might be always running, the ingot first passing between the bottom and the middle roll, and then back between the middle and the top roll, that was a wide question into which he would not enter, but the reason urged against reversal, viz., that it wasted steam, must, he thought, be entirely wrong. Mr. Fernie objected to compound engines because of what he called their slow circulation. He had not, however, proved any slow circulation. Further, Mr. Fernie appeared to be of opinion that a peculiar task was laid on a rolling engine because of the frequency of the blows against the rolls; he had shown by a diagram that within the minute represented by a horizontal line fourteen blows were received against the roll. Mr. Bramwell should have thought the more frequently the blows occurred against the rolls, the more easy it would be for an engine to encounter them. If a blow came once in a day, an engine developing an average of 1 HP. might be troubled with it; if a blow came every minute it would be less troubled, and if every second still less, always taking the whole work done from first to last to be the same. It would be well that such an objection should be supported by instances in which compound engines had been used and found failures. He did not think that any such instance could be brought forward. He believed it would be found that these engines were as capable of rapid movement, and of responding to the demands made upon them, as the very simplest non-condensing, single-cylinder engine ever made. That was his opinion about the compound engine, and until instances were brought to the contrary he should retain it. Many years ago he had suggested what he really believed was the right way to roll rails and all long metal, by a mode which got rid of reversing rolls, or of the rolls three high, and that was the employment of continuous hoop rolling for straight bars. A railway

tire was now made by rolling it in the hoop, and he knew of no special difficulty in making the hoops 10 feet in diameter (they were certainly made 7 feet), which when open would be 30 feet long, and few engineers required a rail to be longer than that. He still believed that the right way of rolling large and heavy sections of steel or iron was to roll them in the hoop form, as was done with tires, and then to cut the hoops and to straighten them. In that way unsound crop ends would be got rid of, and a large amount of material and of labour in manipulation would be saved. Mr. Bramwe

Mr. DRUITT HALPIN observed that Mr. Fernie, in his reference to the Paper by Mr. Kraft, a short abstract of which appeared in the Minutes of Proceedings, had omitted the calculation at the end of the Paper as to the consumption of steam in the case of the three-high or pull-over mill, and what was due to the enormous fly-wheels necessary in the old system. He believed it was about 75 HP., and this would go a long way to account for one of the two boilers of steam, which Mr. Fernie thought were wasted. Mr. Kraft's position was that the average space to be filled at each starting of the mill was about one and a half cylinder, taking the double-crank engines; and that he looked upon as purely waste steam, or space which had been wastefully filled before the work of rolling commenced. From that Mr. Kraft calculated a large loss. In the Le Chatelier brake alluded to by Mr. Bramwell the steam was all re-compressed and sent back into the boiler. Mr. Druitt Halpin.

Mr. E. J. COWLING WELCH said the Paper was a general announcement concerning special forms of hydraulic appliances manufactured by the Author's firm, and applicable to all sorts of purposes other than the special ones indicated by the title of the Paper. The Author had urged that water should be used economically, and he dilated rather upon the material and workmanship of the boilers than upon their design and construction. Economy in the consumption of coal too was apparently regarded as immaterial, it being only considered necessary to evaporate 12 lbs. of water with 2¼ lbs. of coal, or 5·3 lbs. of water per lb. of coal. It could not be the theoretical quantity of water, indicated by the diagram, which was meant, because the Author distinctly alluded to the amount as that which was "required to be evaporated." As the Paper referred to the manufacture of steel he did not understand why the pressures should be limited to 600 and 750 lbs. per square inch, as in one of the most important applications of hydraulic power to steel-making (Sir Joseph Whitworth's) the pressures amounted to some thousands of pounds, and in nearly Mr. Cowling Welch.

Cowling lch.

all workshop appliances worked by water the pressure used was 1,500 lbs. per square inch. Water at a very high pressure, too, froze much less readily than water at a low pressure. He had found that with as little as 1 per cent. of glycerine, water under a pressure of 1,500 lbs. per square inch, and in the lowest temperatures in this country, never became thick or frozen; whereas water, with the same percentage of glycerine, when exposed to the open air at the same temperature, became a sort of rotten ice, which would of course obstruct the machinery. He did not think that engines could be run continuously when driving hydraulic machinery. But it was not economical that the speed should be reduced, or that engines should be stopped by any communication with the accumulator, which acted in the way of throttling the steam. The plan he had tried and found successful was that of a satisfactory automatic expansion gear. When the engines were stopped the expansion arrangement was practically thrown out of gear, and the steam could follow the piston through the whole stroke; this enabled the engines to start at any point, and as they got their speed up the expansion gear came into play. In one plant the engines were geared to the pumps as 3 to 1, and the engines ran one hundred and twenty revolutions per minute, with a piston speed of 300 feet. Of course it was not sufficient that one crank should have just passed the centre before the steam became cut off in the other cylinder. The crank that had just passed the centre must have sufficiently passed it to enable the pressure to overcome the static resistance of the pumps before the engine could start; therefore it was necessary to use automatic gear which enabled the steam to follow the piston late on in the stroke, before being cut off, when the engine was running at a slow speed. A convenient arrangement of this sort, made by the Hydraulic Engineering Company for the Hull docks, consisted of an ingenious application of Correy's cut-off gear to compound pumping engines. Another arrangement that had been found satisfactory was that of driving pumps with a belt, the belt being thrown on and off suddenly by a tumbling gear on the accumulator after it had fallen about one-third of the stroke. The belt was thrown suddenly on to the fast pulley, and similarly when the accumulator got to the top the belt was thrown as suddenly off on to the loose pulley. With geared pumps the same arrangement had been adopted. The accumulator did not start the engine the moment it began to descend, but only after it had fallen through a considerable portion of its stroke. The engine thus had an opportunity of getting into good gear and working expan-

sively with economy. The plan adopted by the Author had been called an alternative one; it was an alternative arrangement certainly, but very complicated. There were four pumps, with six glands to be kept tight, but in the other case there would only be two glands, and two leathers, one on each piston. The suction besides was intermittent and irregular, as shown in the diagram (Fig. B), and in a large pump that was a serious matter, as there was great difficulty in keeping the suction valves in order when the flow of water was irregular through them. The discharge also was exceedingly irregular; the diagram (Fig. C) showed that it rose and fell considerably, giving the accumulator a vertical vibration, which was liable to cause a fracture of some of the connections, and to produce irregular action in the machinery. Piston and plunger pumps were usually fitted with two leathers in each piston, whereas, the pressure being always in one direction, only one was needed; by abolishing one of them the other lasted longer, and much less trouble was given. In an arrangement effected by the Hydraulic Engineering Company, Chester, there were three single-acting pumps driven by a compound engine with a three-throw crank shaft, the circle being divided into three equal parts. There was no internal piping, but simply three glands. The diagram (Fig. A) showed how very regular the discharge of water was. Of course the suction followed exactly the same line. It was much more regular than the two-throw combination pump of the Author's shown in Plate 1, Figs. 1 and 2. The treble single-acting pump naturally led on to Mr. Brotherhood's capstan engine, in which, instead of there being three cranks equally distributed around the circle, the cylinders were placed round one crank, and the action of the water came nearly to an even line, as in the diagram (Fig. A), which was most essential in a capstan engine. In an engine of that kind it was absolutely necessary that the line of pressure should be as regular as possible so as to give a constant force at the surface of the capstan, because the capstan had to start from any position at all sorts of speeds (very slow sometimes), and it had to overcome the static resistance at the surface, the limit of which was tolerably well ascertained beforehand, and the engine proportioned to it. The engine with the four-cylinder arrangement was a reversion to an irregular curve, as shown in the diagram (Fig. C), in which the force exercised by the engine gave a maximum and a minimum, and the variation between these was very great indeed. The minimum must be made sufficient for all that was required, and between that and the maximum there was a great deal of waste. In the three-

Mr. Cowlishaw Welch.

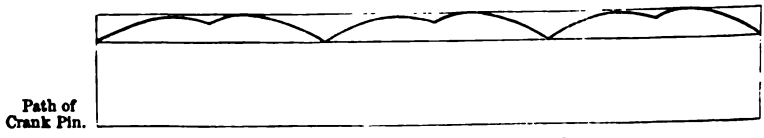
Cowling ch.

cylinder engine the whole was symmetrical, and it was arranged about a central point; there was only one valve; it worked on a seat of lignum vitæ, and there was not the slightest dif-

WATER VELOCITY CURVES FROM PUMPS.

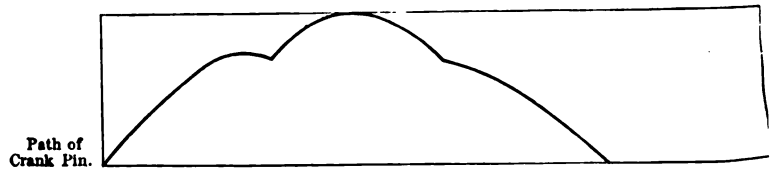
Connecting rod 3 times the stroke.

FIG. A.



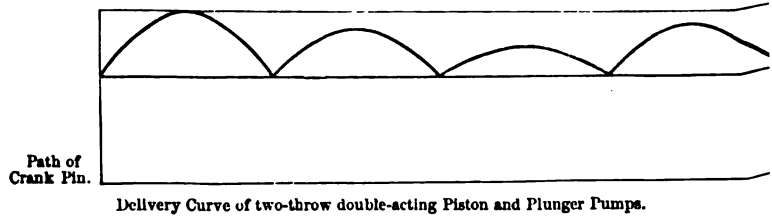
Suction and Delivery Curve of three-throw single-acting Pumps.

FIG. B.



Suction Curve of two-throw double-acting Piston and Plunger Pumps.

FIG. C.



Delivery Curve of two-throw double-acting Piston and Plunger Pumps.

ficulty with it. A large number of them were at work, and, as far as he could ascertain, they gave no trouble at all. There seemed, therefore, to be no object in having a complicated thing with four cylinders and all sorts of arrangements, one engine accommodating the other by working its valve, and so on. Professor Kennedy argued that the fly-wheel and the reciprocating parts of the steam pumping engine might be made much lighter than they were, but he overlooked the fact that their mass was necessary to take up the surplus energy at the commencement of the stroke, and to give it out again during the expansion of the

steam. If expansion was used, a very heavy fly-wheel and reciprocating parts were absolutely necessary. Many attempts had been made to produce an economical hydraulic engine. He had seen Hastie's engine at work in Greenock, in which the stroke varied according to the work that had to be done, and to some extent that met the difficulty. With reference to the cranes, the arrangement shown by the Author seemed to be a very lopsided one. The centre ram appeared to be used for balancing the crane, and to act as a crane-post, whereas the power was applied by a ram out of centre. He had seen a simple arrangement leaving the main ram to do the work, boring it up, forming it into a small cylinder, which worked upon a ram fixed into the bottom of the main cylinder. A passage up the centre of this ram allowed a free communication with the accumulator, and thus the dead weight of the crane was balanced, the difference between the areas of the two rams forming the area upon which the pressure acted to lift the weight. There was no doubt great economy in compound engines, when they could be kept running anything like continuously, but there was some difficulty occasionally when the engines had to be stopped and started frequently and by automatic means. Mr. Cowling Welch.

With regard to what had been said about the material for boilers, he had had a good deal of experience in boilers of steel as well as of iron, and there was no difficulty in making the largest Lancashire boilers 30 or 40 feet long by 8 feet in diameter, or any kind of boiler in steel, provided the boiler makers only understood the handling of steel. The Yorkshire iron of the present day was so unreliable that manufacturers could never be sure of getting a boiler plate that would flange. There was no doubt that steel boilers could be had which would last as long as iron boilers, and never give any trouble. They were cheaper in the first instance, and had very great advantages. If, however, they were made by those who did not understand the matter, there would be a liability to failure. After a plate had been flanged it should be put back into the furnace, and re-heated before it became cool—that was the great secret. He had seen a flat plate flanged without that precaution being taken, and in the middle of the night it flew right across the flange of its own accord. If the plates were well handled, and the several operations well supervised, they would answer thoroughly. If a corner was thinned, and if the plate was not immediately put back and the corner re-heated to a blood-red heat before being put on one side, the chances were that the corner would fly off or would be easily knocked off.

rwhing

Something had been said about cup-leathers not standing. If a cup-leather was worked in a gun-metal cylinder, and was properly proportioned and made, there was no difficulty in getting it to stand. He had known them last a year and a half in constant wear without showing any sign of giving way.

Taking everything into consideration, it appeared to him that nothing in the Author's engines and pumps offered any advantages over those of other makers.

utler.

Mr. W. H. CUTLER said he had used gutta percha instead of cup-leathers for fifteen or sixteen years, and had found it answer very much better. It lasted four times as long as leather, and when it was worn out, it was still good for something, because it only wanted a small quantity of gutta percha added, and when it had been warmed and pressed in the mould it came out as good as new.

ham.

Mr. ARTHUR RIGG had calculated the differences in driving power of the two-cylinder and three-cylinder hydraulic engines; for all practical purposes they were the same, though relatively different, the power being as three in one case to two in the other, so that the three-cylinder engine had relatively only two-thirds of the differences existing in a two-cylinder engine. These proportions were, however, considerably modified when the connecting rods differed in their proportionate lengths in the two- or three-cylinder engines. In the cranes shown in the Paper (Figs. 5 and 6), there were two rams besides the centre one. He did not see why one of the smaller rams might not have been put underneath. In Figs. 11 and 12 there was a worm and worm-wheel, which had given rise to a great deal of discussion. It appeared to be an excellent mechanical self-acting locking arrangement. It was not a desirable thing to have so large a quantity of melted metal without any better protection from overturning than that afforded by a ram. The Author's arrangement seemed very secure for the purpose intended, whereas a ram was more suitable for cranes.

Contrary to the many opinions expressed with regard to compound engines, he desired to say a few words in favour of simple engines. The engine shown by the Author ran at a low speed simply because the pumps had to go slowly. There were three sorts of engines using high ratios of expansion. There was the Corliss engine, which might be taken as a pattern of scientific mechanical working, and there was the Cornish engine to which allusion had been made. The last-named of these, so far from being antiquated, was only single-acting, and the Corliss engine, which had produced such admirable results, was double-acting. In the Cornish pumping engine high-pressure steam was employed,

with great expansion and an enormously heavy mass to move; and some of the initial pressure of the steam was absorbed in the first instance in moving this mass, and it carried the piston over to the end of the stroke when the steam pressure was reduced by expansion below the mean required to move the pump rod. It was just the same in the high-speed steam-engine. There was a regular uniformity of pressure in the compound engine which was well adapted for what he might call the weak design of ordinary steam-engines. The three types might be taken as practically nearly the same in point of economy; it was not, therefore, a question of principle whether an engine was compound or simple, but only a matter of mechanical convenience for working with high expansion, because after all it was the high expansion of steam that gave economy, other things being, comparatively speaking, indifferent. In many of the northern mills the compound engine was getting into disfavour, and the Corliss, or other high piston-speed engines were being substituted. He had recently seen, at Messrs. Illingworth's mills at Bradford, a Corliss engine with a single 40-inch cylinder with 10-feet stroke, and it made 900 feet per minute piston speed. It was driving a large mill with the utmost regularity, and developing upwards of 840 indicated HP. The engineer informed him it had been driving the mill better than the first, a coupled engine, had done. He had some experience with high piston-speeds obtained by a comparatively short stroke and increased number of revolutions. It was a matter of nice calculation to get the steam-pressure applied and the weights of the moving parts properly adjusted to each other. In order to get a high speed and a regular uniformity of motion, it was absolutely necessary to have a sufficiently high pressure of steam. He had working at Liverpool one engine of his own design, with 14-inch cylinder and 21-inch stroke, making one hundred and fifty-two revolutions per minute, with 60 lbs. per square inch boiler pressure, and indicating rather over 60 HP. It was doing most irregular work with the utmost steadiness. Another, just started, had a 16-inch cylinder, and, at a piston speed of 640 feet per minute, working with 90 lbs. of steam per square inch, indicated over 100 HP. It was used for driving millstones, and if there was one test for an engine more severe than another, it was regularity in driving millstones. He listened carefully, and he could not detect the slightest variation in the sound of the gearing. The fly-wheel weighed nearly 4 tons, and the engine ran one hundred and sixty revolutions per minute; indeed it had run two hundred revolutions, and it was surprising to see how quietly

Mr. Rigg.

Rigg. and steadily everything worked. The economy of these engines was good, but he had not been able yet to test this class of engine upon a large scale. He had a 12-inch cylinder engine, working some time ago with a pressure of 90 lbs. per square inch, and the coal consumed was about 2½ lbs. per indicated HP. per hour. These examples would show that the employment of compound, single-acting Cornish, or high-speed piston engine, was nothing else than a matter of mechanical convenience for the use of steam at high rates of expansion, and there was no special merit in compounding as a principle.

Peter herhood. Mr. PETER BROTHERHOOD had no wish to criticise the ingenious hydraulic capstans shown by the Author, but he should like to say something in defence of the three-cylinder against the two-cylinder engine. The three-cylinder capstan was first made by him in July 1873. He then put one down at the London and North-Western railway goods shed at Broad Street, and the result was so satisfactory that the company now had one hundred and forty-three of them at work at their various stations. He also supplied one in 1873 to the Bolton Iron and Steel Company. A few months ago, in making some alterations at the works, it was taken up and sent to him for examination before being refixed. After six years' continuous work it was practically in as good a condition as when it was first put down. It had never been taken apart, except to replace leathers, of which only three sets had been used. It was worked at a pressure of 350 lbs. per square inch. The pressure at the London and North-Western railway stations was 750 lbs., and at the Toulon Dockyard, where the machines were used in connection with some plate furnaces, the pressure was 1,500 lbs. In all the cases he had mentioned, they had given great satisfaction. The capstan required little attention. There were no glands to be kept tight, and no joints to screw up. The working parts were oiled from the top through the crank-shaft; and that was all the attention needed. The working parts were extremely simple. The connecting rods were made of cast iron in one piece. The central hole was bored, leaving a thin film of metal between them. The rods were then broken apart, and the ends trimmed with a file, and the butt ends rounded up to work as a knuckle-joint in the rams. There was one advantage in the system not possessed by the other, that the capstan might be used as a dummy where, in a series of capstans, it was required to carry a rope in different directions, because it revolved so freely. The [redacted] were left at the back end of the cylinders, and revolved [redacted]out any friction. With regard to simplicity and accessibility

of parts, he might mention that he had seen a capstan taken to pieces, and had had every piece in his hand for examination, and put back again and at work in twelve minutes. Mr. Peter Brotherho

Mr. B. WALKER, in replying, said that a good deal of time had been expended in the endeavour to disprove what he had never said. He had never said that 12 lbs. of water were sufficient; he had said that he had compared a large number of indicator diagrams, and he had given the results. His only object had been to raise compound engines in the estimation of engineers; for, notwithstanding the remarks of Mr. Cowper and others, who seemed to look upon the thing as a foregone conclusion, people would not buy them, but wanted something cheaper. With regard to the capstan engine, he had no desire to compare it with any other. Nor would he refer to the remarks of those who considered his arrangement of ingot crane as "lopsided," that there were six glands to keep tight, and so on. He had had some experience in this class of machinery, and he had only brought forward his views for the information of the members. He might, however, be permitted to refer to the turning over of the converter. Some weeks ago he was standing alongside a Bessemer pit, and hearing a terrible cry he looked out, and a man was calling attention to a red spot on the side of the converter. "Look out," he said, "the converter lining is giving way, and you will have the metal out." They then considered what was best to be done. If the man could have turned the converter the contrary way, the lining would have been saved. As it was he could only turn it one special way, and the result was that all the metal came out into the pit, and a great explosion took place, involving a terrible amount of destruction. There was nothing mechanically in connection with the Bessemer process that had given more trouble than the want of control in the arrangement of tipping by rack and wheel, and the power to turn the converter either one way or the other. With reference to the crane (Figs. 5 and 6), the centre ram was not, as had been suggested, simply a guiding ram. The specification stated that water was admitted through to the bottom, and the concentric area was nearly sufficient to balance the whole crane. The lifting part of the crane weighed about 6 tons; the actual maximum load intended to be lifted was 4 tons. The load lifted in the Bessemer pit was generally only 1 ton. With the crane that Mr. Ellington thought best, 10 or 11 tons would be lifted at every stroke, and a corresponding amount of water would be used. Mr. Walker only used water corresponding to 1 ton. With reference to the remarks of Mr. Mr. Walk

Walker. Tweddell, as to the employment of rotary engines, he could only say that he never used a rotary engine where the same result could be obtained from a direct-acting ram. Mr. Tweddell had expressed an opinion that Sir William Armstrong's direct-acting ram was the most convenient and economical, but he must have overlooked the fact that the movement of the jib about which he inquired was shown by the drawing to be moved by a direct-acting ram. In the Paper it was mentioned that it was so done, and Sir William Armstrong's expression "jigger" was used.

Many years ago he had said that steel for boiler plates was not what it should be, and he had since then paid great attention to the subject. During the last three months he had seen, over and over again, steel produced by the Siemens process made into boilers such as he had never seen before. The steel would weld and bend and do anything that the best Low Moor iron would do, and at a less cost. Steel plates were as soft and weldable and as kindly in their nature as iron plates. The progress made in that direction during the past few years had been enormous. The great point to aim at was to get a uniform elastic limit, and to give a chance of a little change in structure taking place without permanent detriment. In the future boiler plates would be made of steel, using the same care in manipulation as was now used by the Low Moor and other Yorkshire iron makers, only instead of using the refinery and puddling furnaces, the Siemens or Bessemer process would be adopted, and the bit-by-bit process given up. In his opinion the introduction of steel had been greatly retarded by the desire to have a very high elastic limit and breaking strain, and when the steel was made to carry a very heavy strain it was invariably hard and not so reliable. He thought the value of annealing boiler plates had been much overrated. He would never put plates into a boiler that were so brittle that, if after drawing the corner down, he was compelled to anneal the whole plate to prevent the corner from flying off. If the plates were not of proper material, no amount of annealing would change the composition of the steel. The amount of work, hammering, pressing or rolling, greatly affected the quality of the steel plate; generally boiler plates did not receive a sufficient amount of work. Many years ago his firm had a number of Lancashire boilers to make, and the designer of these boilers determined that one flue in each boiler should be altogether of steel, the other of best Yorkshire iron. The steel plates were ordered of Messrs. Charles Cammell & Co. The chairman of this company informed him, after receiving the order, that it would be necessary to drill all the holes and

anneal the plates after they had been cornered and bent. Mr. Walker reminded him that he had said that his steel was as good as best Yorkshire iron, and it would and did receive exactly the same treatment. The boilers were made and tested to the satisfaction of the engineer, and had now been at work many years without any difference being detected betwixt the steel plates and the best Yorkshire plates. Of course neither the best Yorkshire nor the steel plates received any unreasonable treatment; drifting and "kinking" or setting when cold was avoided. Mr. Walker

With regard to the remarks made by Dr. Siemens and Mr. Cowper, in the main he agreed with them, except those in reference to the cogging engines. He was sure it would be better to do away with the wheels; there would be less wear and tear. He proposed to run the rolls only at the ordinary speed; the whole machines, engines and gearing, cost as much one way as the other. When the engines were constructed without wheels, they could be used to cog, rough and finish, and where say only 1,000 tons of rails per week were required this would be a great convenience. With regard to the remarks of Mr. Fernie as to the kind of mill to be used for steel-rail rolling, he would rest content with stating that in his opinion the two-high mill with reversing engines was the best, needing the fewest men and the least steam. The engines, of course, should be compound, and fitted with surface condensers; the saving of first cost in boilers would pay for making the engines in this way. Compound engines could be made to work at the same speed as non-compound engines; and the complication was not to be mentioned in comparison with the saving. He wished to direct special attention to Mr. Cowper's remarks about the relative economy of compound engines. Dr. Siemens and others had referred to the pressure which he said he had found most suitable for the ordinary hydraulic machinery, viz., 700 lbs. per square inch. Mr. Walker was well aware that Sir William Armstrong had adopted that pressure generally many years ago, and in his opinion Sir William had done more than any one else towards the invention and perfecting of hydraulic machinery; but he did not know why Sir William had adopted that pressure for this class of work. Mr. Walker's reasons were, that at pressures above 700 lbs. per square inch, the various valves, though made of the hardest and best material, gave trouble, and even at that pressure considerable skill and experience were required to keep them right. For other kinds of hydraulic machinery, such as for armour-plate bending, steel pressing and squeezing, he had used pressures from 700 lbs.

Walker. to 8,000 lbs. per square inch. He was at present engaged in constructing a large press for bending armour plates and pressing steel, and in this case he had adopted a pressure of 5,600 lbs. The cylinders were 3 feet in internal diameter, and were being made by Messrs. Charles Cammell and Co., of the best quality of Siemens mild steel.

He regretted Sir Henry Bessemer had not been present. Some of the members might think he ought to have made greater reference to him. The absence of more frequent reference to his name arose from no want of appreciation of the immense benefits rendered by his process, not only chemically but mechanically. No engineer having any knowledge of what Sir Henry had done could go through the modern contrivance without seeing that he had been in the same field before, and generally inquirers had to tread in the same path with very slight variation; in fact, his handiwork was met with at every stage.

Correspondence.

Percy stmacott. Mr. PERCY G. B. WESTMACOTT stated that condensing engines were first applied to high pressure pumping engines in connection with Sir W. Armstrong's hydraulic system about fifteen years ago; but it was not until the price of coal rose considerably that engines of this class came more into use, at any rate in this country. The late secretary of the London and St. Katherine's Docks, Mr. T. W. Collet, who was by profession an engineer, first introduced the compound engine, with a high rate of expansion and surface condenser, at the Victoria Docks, in the year 1873. This engine gave off 140 actual HP. from the pumps. The high-pressure cylinder was 14 inches in diameter, the low-pressure cylinder 28 inches, and the stroke 38 inches long. Steam was cut off at half stroke in the high-pressure cylinder, and there were eight volumes of expansion boiler pressure at 60 lbs. per square inch. Another similar engine had lately been added to these docks. These engines would run up to sixty-four revolutions per minute, giving a piston speed of about 400 feet per minute. The accumulator pressure was 750 lbs. per square inch. The force pumps were of the plunger and piston type. Respecting piston speeds, it was the common practice at Elswick to allow for a mean of from 260 to 360 feet per minute; but in certain positions where economy of space was of paramount importance, as for instance on board ironclads, a rate of 450 feet per minute was attained. This particular class of engine

Mr. Percy Westmacott

was made very compact, with no fly-wheel, was generally used without an accumulator, and arranged to answer the action of the throttle valve quickly, from a creeping motion of about five revolutions per minute to one hundred and eighty. They could be made to start and stop instantaneously. Engines of this type had been constructed up to 160 actual HP. given off at the pumps, and were got into a space of 9 feet 9 inches by 7 feet 5 inches high. There was no undue heat upon the valves at high rates, the valves and passages being specially made and proportioned for such rates; nor in valves so constructed was there any undue wear and tear. It certainly was most desirable to introduce the high class of compound condensing engines wherever practicable, but there were situations and conditions in which a lower type was preferable, and, all points considered, they were probably quite as economical. These conditions depended altogether upon local requirements, the amount of work to be done, and the nature of such work. It was not easy to arrive at a reliable comparison of the cost of producing high pressure water between the different types and forms of pumping engines, as so much depended upon the conditions under which engines were worked in connection with intermittent acting machinery. The data of a trial, given by the Author, with engines at the East and West India Docks, assumed a condition which could not occur in practice. In this instance he calculated the cost of producing 1,000 cubic feet of pressure water of about 700 lbs. per square inch with the above engines, including all expenses, excepting the cost of the boilers, to be about 4*s.* 3*d.*, and that of the ordinary type of high pressure non-condensing engines to be 6*s.* 7*d.* per 1,000 cubic feet. In both cases the price of coal was taken at 8*s.* per ton. At the Poplar docks, London, there was a plant of six ordinary high-pressure engines. A record of the cost of working these engines since 1878 was given below. In this case the pressure was 700 lbs. per square inch, the cost of coal being about 14*s.* 6*d.* per ton.

Year.	Number of Gallons pumped.	Tons of Coals burnt.	Cost of Coal, Wages, &c.	Cost per 1,000 Cubic Feet.
			£. s. d.	s. d.
1878	55,201,168	1,821·05	3,023 5 9	6 7
1879	69,422,339	2,097·75	3,220 11 10	5 7
½ of 1880	38,895,340	1,105·30	1,627 8 5	4 11½

Percy macott.

To this must be added wear and tear and interest upon the outlay of capital, which would add about 1*s.* 6*d.* to the cost of producing 1,000 gallons to the item in 1878, and so much less in proportion to each succeeding period. It would be observed that as the work of the dock increased, the cost of producing the power diminished; and as the engines were not yet worked up to their full power, it might be inferred that the limit of cost of water was not yet reached. Another reliable instance of the cost of pumping pressure-water with the ordinary type of engines, which were worked well up to their full power, might be taken from results at the Cardiff docks. Here the pressure was about 700 lbs. per square inch, and the cost of pressure-water, including fuel, stores, and working expenses, was 3*s.* per 1,000 cubic feet. With regard to working pressures for hydraulic machinery, it was still found that the pressure which Sir W. Armstrong decided upon more than twenty-five years ago, viz., about 700 lbs. per square inch, was the most serviceable for general work, embracing varieties of machines such as were to be found in plants for dock and railway purposes, but pressures reaching up to 15,000 lbs. per square inch had been employed for special purposes. In respect to packings for hydraulic rams or pistons, he preferred leather wherever this material could be conveniently applied. Great care, however, must be taken in the selection of the leather, in the form and construction of the lips of the leathers, and in the care with which the leather was inserted into place. Piston leathers had been known to wear in constant working engines for four years or more, but, on the average, the life of a leather might be taken at six months. It did not occupy more time, if so much, to renew a leather as to renew a hemp packing; the latter description of packing was more serviceable for rams of cranes and accumulators, or such machines. The peculiar arrangement of force pumps and rams for the steam-engine mentioned by the Author did not, in his opinion, save the liability of leakage from the pressure to the suction, as the water was free to pass the middle packing without detection. Nor was the cost, compared with a gun-metal lined pump with piston and plunger, at all in favour of the ram arrangement, as the engine had to be increased considerably in length to take in the double rams.

Price liams.

Mr. R. Price Williams thought it would be generally admitted by those who had any practical experience in the construction and working of the machinery used in the manufacture of Bessemer material, that, next to the great principle involved in the process of the conversion of the cast iron into steel, what had

Mr. Price Williams.

contributed most to its rapid and unprecedented success had been the application of the simple and ingenious hydraulic machinery designed for the purpose by Sir Henry Bessemer. Although Mr. Price Williams had not for some years been actively engaged in the construction and working of Bessemer plant, it had been his privilege to assist in carrying out, under Sir Henry Bessemer's directions, the erection of Bessemer plant embodying some of the inventor's latest improvements, and he had never ceased to take the deepest interest in everything affecting the further development of the process. In his own experience he had never seen anything more simple and economical than the hydraulic machinery which Sir Henry had designed, and he was glad to find this opinion shared by Mr. W. Hackney, Assoc. M. Inst. C.E., who in a comprehensive paper, read at the Institution in 1875, thus referred to it.[1] "The machinery of the Bessemer process is well known and need not be described here; it still remains almost exactly as Mr. Bessemer designed it. . . . . Increased output has rendered alterations necessary in other details, such as the provision of increased crane power, better ventilation of the working places, and greater facilities for bringing in and handling materials, and for taking away the ingots and the refuse; but in all essential points, and to a remarkable extent, the Bessemer process and the Bessemer machinery are still in use as they were planned by the inventor—the offspring of one master-mind." The same had been remarked by another writer on this subject, Mr. Jeans, who in his recent work on steel, observed that: "It is noteworthy that while most great inventions or appliances have from time to time, as the outcome of better knowledge and more matured experience, been modified and altered, the appliances originally designed by Bessemer, on the first practical application of his process, continue, in principle, to be adhered to to the present day."[2]

Under these circumstances, he had noticed with much regret the absence of any recognition by the Author of the fact that the hydraulic machinery which he had described was, in all essential particulars, what had been originally designed by Sir Henry Bessemer. The Author, referring to some of his improvements in the Bessemer machinery, had alluded to the worm and worm-wheel arrangement, for moving the converter, as being a new feature; but this was practically identical with the arrangement

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlii., pp. 19, 20.

[2] *Vide* "Steel: its History, Manufacture, and Uses." By J. S. Jeans, 1880, p. 364.

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patented by Sir Henry Bessemer in February 1869, as might be seen by comparing Fig. 11 with the original drawing.

As regarded the converter used for the Thomas and Gilchrist process, described as the "Haycock Converter," it would not have escaped the recollection of those who remembered the early experiments at St. Pancras, that this was nearly the form of converter used there, as well as at Sir John Brown's works at Sheffield, the inclined shape of the Bessemer converter subsequently adopted having been designed to prevent the slag and other products of combustion projected from the converter from falling back into it. He should be glad to learn how this was provided against in the "Haycock Converter."

Twenty-two years ago Sir Henry Bessemer read a Paper at the Institution,[1] descriptive of his process, when he exhibited samples of the new material, and stated some remarkable results obtained by Colonel Eardley Wilmot, from tests to which it had been subjected at Woolwich. The opinion then expressed, as to the practical success of the process and the superior quality of the material, was, with one notable exception, highly favourable, an opinion which later experience had confirmed. Not only did the process furnish a much stronger and better class of material, but one in every way more reliable than the best class of iron, which it had now to a large extent superseded.

The Paper of 1858, by Sir Henry Bessemer, had been fitly supplemented in 1875 by the Paper by Mr. Hackney, already mentioned, and he certainly considered that any Paper dealing with the comprehensive subject of the machinery employed in the Bessemer manufacture, should have reference not merely to particular improvements or modifications in the machinery effected by the Author, but to those which had been adopted at other works, and notably at some of the principal works in the United States of America.

Very few data were afforded in the Paper for testing the economical results stated to have been obtained by the substitution of compound engines for single- and direct-acting engines, such as the Corliss engines at present in use at Crewe, and almost universally adopted, both for the hydraulic and blowing apparatus. Such data, however, as had been given were, he considered, of a very questionable character. For instance, there must evidently be some mistake in regard to the 168 lbs. which, according to the Author, Mr. Martin, of the Blaenavon works, had informed him was the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., p. 525.

total quantity of coal used per ton of steel made, including the coal required for the hydraulic engines for moving the Bessemer apparatus, and when these engines were doing full work. To prove this, it was only necessary in the case of the 300-HP. hydraulic engine, to apply the 2¼ lbs. coal consumption per indicated HP., which the Author quoted as being the result of numerous trials made with them; this would give 300 × 2¼ lbs. = 675 lbs. of coal per hour when doing full work. Now the number of Bessemer "blows" which a pair of the most modern 10-ton converters could accomplish in the course of twenty-four hours was about twelve, which would represent just 5 tons per hour for both converters, so that the total quantity of coal consumed by the 300-HP. hydraulic engines, when in full work, would alone represent $\frac{675}{5}$ lbs. = 135 lbs. per ton of steel made, and this amount deducted from the 168 lbs. would leave only 33 lbs. of coal as the coal required for the cupola, furnace, and blowing engines. This was manifestly insufficient, the average quantity of coke alone required in melting the pig iron in the highly economical cupolas invented by Mr. Cooper, and which utilized the waste heat of the converters, amounting, according to Mr. Holland, to under 155 lbs. per ton of pig iron charged,[1] which was equivalent to about 183 lbs. per ton of the ingot steel produced. Mr. Price Williams.

Then, as regarded the hydraulic pumping engine, the Author stated that the cost of producing 1,000 cubic feet of water, at a pressure of about 700 lbs. per square inch, with his highly expansive surface condensing engine, was about 4*s.* 3*d.* Now since a pressure of 700 lbs. on the square inch corresponded to a head of 1,600 feet of water, and 1,000 cubic feet of water represented 6,240 gallons, it followed that 1,000 cubic feet of water, at 700 lbs. pressure, were equivalent to 6,240 gallons pumped to a height of 1,600 feet; so that this cost of 4*s.* 3*d.*, in equivalent terms, might be stated as 0·51*d.* per 1,000 gallons, if pumped a height of 100 feet, which certainly could not be said to represent a very economical result for this class of work. Mr. Bramwell, in giving evidence before the Fire Brigade Committee,[2] had stated that the ordinary cost ranged from ⅓*d.* to ½*d.* per 1,000 gallons pumped to the height of 100 feet.

Whilst in no way disputing the economy resulting from the use

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[1] *Vide* The Journal of the Iron and Steel Institute, 1878, p. 109.

[2] *Vide* Minutes of Evidence taken before the Select Committee on Metropolitan Fire Brigade, 1876, p. 439.

Price Williams. of compound engines, such as described in the Paper, he was disposed to question whether a series of careful and reliable experiments would have shown any appreciable saving when applied in connection with the working of the Bessemer process, having regard to the very brief and intermittent character of the operations which these Bessemer blowing engines had to do. In his opinion, any further additions to those large economies which had been already effected in the production of steel must be looked for rather in the direction of such efforts as had recently been made by Mr. Holland, and Mr. Alexander Wilson, of Sheffield, in utilizing the waste heat of the converter and cupola, and, he would add, of the blast furnace also.

Walker. Mr. WALKER, in reply upon the correspondence, observed that Mr. Westmacott's remarks were useful and of great value, being founded on his extensive experience. He need only refer to one point, viz., a well-packed gland did not require the same attention as a cup leather. He had found that when the ram did not leak at the front, or in sight, it did not leak from the pressure to the suction or through the middle packing. He was surprised Mr. Williams should have imagined that he desired to say or do anything detrimental to the great honour due to Sir Henry Bessemer, whose reputation was so great that it was unnecessary to add to what the members were well aware of. With regard to the 168 lbs. of coal per ton of steel, Mr. Williams seemed to have overlooked the fact that at Blaenavon the work was done direct from the blast furnace, and that therefore no cupolas were needed. Mr. Walker distinctly reasserted that the 168 lbs. of coal required were for the Bessemer blowing engines and hydraulic engines for moving the Bessemer apparatus. To prove that he was wrong, Mr. Williams started with the assumption that the 300 HP. engines referred to in the Paper were necessary to drive the Bessemer plant working at Blaenavon; this was not the case, the engines at work at Blaenavon were much smaller than those referred to in the Paper. He had not said that these engines were at work there. With regard to the cost of producing pressure-water, he considered the circumstances of the case adduced so different from what he had brought forward that the comparison was not a fair one. Finally, Mr. Williams admitted the value of the compound system. From his experience the ordinary Bessemer blowing engines required six large boilers to drive them, but the engines described in the Paper required only four, giving a saving of more than £1,000 in the first cost, besides the daily expense of supplying coal, labour, and wear and tear to two boilers.

16 November 1880.

WILLIAM HENRY BARLOW, F.R.S., President,
in the Chair.

The discussion on the Paper on "Machinery for Steel-Making by the Bessemer and the Siemens Processes," by Mr. WALKER, occupied the whole evening.

23 November, 1880.

WILLIAM HENRY BARLOW, F.R.S., President, in the Chair.

(*Paper No. 1696.*)

"New Zealand Government Railways."[1]

By JOSEPH PRIME MAXWELL, Assoc. M. Inst. C.E.

PART I. WELLINGTON TO WOODVILLE (Plate 4).

THE railway from Wellington to Woodville was one of the first projected in a comprehensive scheme of public works undertaken by the legislature of New Zealand in 1870.

The railways were proposed to be of a cheap description. A gauge of 3 feet 6 inches was decided upon; sharp curves and steep gradients were to be adopted to lessen the first cost, and suitably low speeds were to be adhered to in working. As indicating the ideas of the authorities the colonial treasurer, the Hon. Julius Vogel (now Sir Julius Vogel, K.C.M.G.), in his financial statement in 1870 described the light railways of America as illustrating the class of line proposed; and in estimating the cost he assumed £5,000 a mile for ordinary lines with a special provision for exceptionally heavy works.

In 1871 the New Zealand Government engaged Mr. John Carruthers, M. Inst. C.E., as engineer-in-chief to execute this scheme, with Mr. John Blackett, M. Inst. C.E., as assistant. Wellington is situated on Port Nicholson, which lies in a fork formed by two mountainous ridges diverging from the Tararua mountains; the latter with an elevation of 6,200 feet being part of a chain reaching from Cape Terawiti in Cook's Straits to the East Cape. East of the Tararuas a fertile country extends from Featherston to Napier. The railway opens this district to the port of Wellington, crossing the eastern arm of the fork in which Wellington lies, and which is called the Rimutaka range.

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[1] The discussion upon this Paper was taken in conjunction with that upon the Ceylon Government Railways.

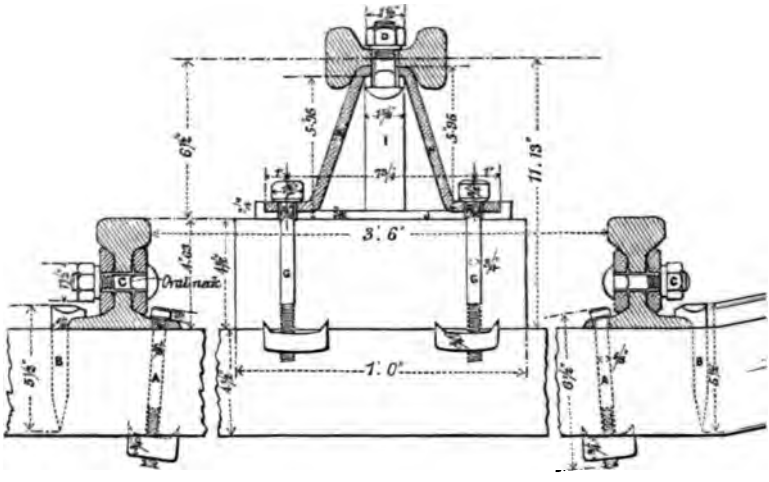
n leaving Wellington the line skirts the shores of the port and es up the Hutt valley to the 19th mile, where it has an elevaof 202 feet, without any special features. Thence it follows flank of a spur rising 1 in 35 to the Mungaroa flat at the mile; at the 23rd mile it commences to skirt the flank of Rimutakas, reaching the Mungaroa saddle at the 26th mile; the 29th mile it enters the gorge of the Pakuratahi, a ntain torrent, and follows the side to the 32nd mile, where gorge narrows to a cleft, and the line is close to the level of bed of the stream; passing thence into a small open valley the s of the mountain spurs are followed up to the saddle at the mile. There are three determining points on the route, viz., Mungaroa flat, the Mungaroa saddle, and the Pakuratahi gorge, ch could not be departed from without disadvantage. From summit the line descends by an incline worked with centre-engines to the plains, reaching an easy country in about 2½ s, and emerging on to the plains about the 39th mile. After ending to 6 feet above high water level, it rises again to about feet above high water at Featherston station at the 45th mile. he gauge of the line is 3 feet 6 inches. On the first 19 miles b. rails are laid, and on the remainder, excluding the Fell ine, 53-lb. rails are used; those on the incline weigh 70 lbs. yard, and are of steel; the centre one is double headed and side rails are of the Vignoles pattern (Figs. 1 and 2). The ks have a formation width of 12 feet, and the cuttings of 10 to feet, according to the ground. Curves of 5 chains radius are ly used, as flatter curves could only be obtained at an extraant outlay of time and money. Appendix I. contains the ticulars of the curves between the 19th mile and the 41st .

he Rimutakas are composed of friable clay slates and sandes of the upper Paleozoic formation, and are densely wooded; r are rugged and precipitous, and on the eastern side fall very uptly to the Wairarapa plains. Topographically they consist ong leading spurs from the main range, with minor ridges at t angles, the natural slopes of the upper hillsides being freutly 1½ to 1, and often 1 to 1. Hence in descending from the mit level, if flat gradients had been adopted and the higher ntry followed, the line would have passed through the secondary s and ridges, demanding sharper curves and much heavier ks than are necessary at the lower elevation.

efore the railway was explored only one saddle through the e was known, its height being 1,820 feet above sea level,

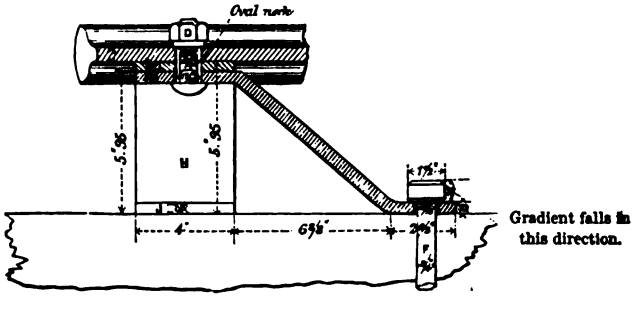
and over this the coach road from Wellington to the east coast was carried. In 1871 the range was thoroughly examined by Mr. John Rochfort, under the direction of Mr. John Blackett, then

FIG. 1.



Transverse section of permanent way on the Fell incline.

FIG. 2.



Longitudinal section of centre rail and bearing tie.

acting engineer-in-chief, and a saddle 1,448 feet above the sea was found. The explorations were continued under Mr. Carruthers on his arrival in the colony. Three routes were considered, one by the road saddle, one by the Rochfort saddle, and one by the coast. The coast line was deemed to be impracticable; the passage by the road presented great difficulties and did not obviate the use

of very sharp curves and steep gradients. Rochfort's route proved to be the best, but the summit level was lowered to 1,141 feet by a tunnel.

Investigations were made, extending over twelve months, to fix the best place of descent on the Featherston or inland side. These comprised, amongst other things, running four trial lines, one at 1 in 40, two at 1 in 30, and the fourth at 1 in 15. The trial surveys from the summit to Featherston showed that the flatter gradients carried the line into the gorges on the face of the range, giving between 8 and 9 miles of exceptionally heavy work through a dangerous and impracticable country: for example, a gradient of 1 in 40 would have involved a succession of curves chiefly of 3 chains radius, often reversing on the same point; and even with these there were nineteen tunnels in 8½ miles, and many embankments 100 feet deep at the centre line. On the other hand, by the gradient of 1 in 15, on which the railway is built, the descent is accomplished in 2½ miles, with comparatively few curves of 5 chains radius, and only two short tunnels. Moreover, the line followed a sound formation, and though ordinarily the works on it would be thought heavy, they were easy in comparison with those required on the other routes.

These considerations led the chief engineer to adopt the gradient of 1 in 15, which it appeared to him could be more cheaply constructed and maintained, and more satisfactorily worked on the Fell system than an ordinary line could be on the flatter gradients. Endeavours were made to find a suitable position for working fixed engines, but without success. It is estimated that the saving in construction by adopting this gradient was not less than £100,000, equal, at the rate of interest which the colony pays for its loans, to £5,000 a year.

There are four Fell engines; their weight and capacity were adopted on the advice of the consulting engineers, Messrs. Hemans and Bruce, MM. Inst. C.E. (Plate 7). Their weight in working trim is 36 tons each. The diameter of the ordinary cylinders is 14 inches, with a length of stroke of 16 inches. The diameter of the vertical driving wheels is 2 feet 8 inches. The diameter of the horizontal cylinders is 12 inches, with a length of stroke of 15 inches. The diameter of the horizontal driving wheels is 22½ inches. The heating surface of the tubes is 783 square feet, and of the fire-box 74 square feet. There are four ordinary coupled wheels, and the same number of horizontal coupled wheels. A central buffer is adopted. The tractive power for each effective pound of pressure per square inch in the cylinders is 98 lbs. for

the vertical and 96 lbs. for the horizontal drivers, total 194 lbs. The consulting engineers expressed their opinion that one of the locomotives would draw 64 tons, excluding its own weight, up the gradient of 1 in 15. The Author found from trial that under favourable circumstances one engine took 63 tons, thus:—

	Tons. cwt.
Two loaded trucks in front	19 10
Four „ behind	39 0
One brake van	4 10
Total	63 0

From the records of a number of trips in ordinary working, two examples have been selected. The loads were above the average. Australian (Newcastle) coal was used, which was found by analysis to consist of—

Fixed carbon	55·36
Volatile matter	31·69
Water	3·00
Ash	10·05
	100·10

The distance run was 201 chains, and the vertical lift was 861 feet.

Example No. 1.

	Tons. cwt.
Load: Nine vehicles	36 10
Goods	19 11
Engine	36 0
Total	92 1

Example No. 2.

	Tons. cwt.
Load: Eight vehicles	24 19
Goods	31 14
Engine	36 0
Total	92 13

In the first example, the rails were dry, the time occupied on the journey was 30 minutes, and the fuel consumed was—coal 4½ cwt. and coke 3 cwt. In the second example, the rails were greasy, the time on the journey was 32 minutes, and the fuel consumed was—coal 5 cwt. and coke 3½ cwt. In both cases a pressure of 150 lbs. per square inch was maintained in the boilers.

In ordinary practice a gross load of about 53 tons, exclusive of the engine, is sufficient; with it the engine can stop and start on 5-chain curves and attain a speed of about 6 miles an hour. A load of 14 tons 5 cwt. has been drawn up the incline without making use of the horizontal driving wheels.

The engines have ample steaming capacity, and a boiler pressure

0 lbs. is maintained; with an effective pressure in the ler of ⅘ of this pressure the tractive power would be 3 lbs. The weight available for adhesion, and the adhesive ıre attainable through the horizontal driving wheels are not n to the Author; but experiments show that the tractive · which can be developed and maintained is slightly in ı of the adhesive capacity.

ıas been stated[1] that the ordinary load of a 37-ton engine on dient of 1 in 27 on the Mauritius railways was 60 tons, and ı 48-ton engine on the same line took a test load of 83 tons. :hat on the Madison incline, Indiana, on a gradient of 1 in ten-wheel coupled locomotive took in ordinary practice a equal to its own weight, viz., 50 tons.[2] Comparing these s with the performances of the Fell engine, it will be found he proportion of the weight of the engine to the gross load ı it draws, excluding its own weight, is:—

Mauritius	37-ton	engine	. . . . .	1	to	1·62,	on 1 in 27
„	48	„	. . . . .	„	„	1·73	„
N. Z. Fell	36	„	. . . . .	„	„	1·42,	on 1 in 15
Madison	50	„	. . . . .	„	„	1·00,	on 1 in 16½

the Mont Cenis line the Fell engine weighed about 20½ tons, rew a load about equal to its own weight up an incline of 1

e Wellington line is at present open only to Featherston, e it taps a large district as yet undeveloped, through which xtension of the line is now being pushed on.

e working statistics for a period of twelve months before ening of the incline, and for a similar period during nine ns of which the incline was in work, are approximately as r:—

	Before opening of incline.	After opening of incline.
Miles of line open	28	45
Train-miles run	69,133	128,200
Total receipts	£16,100	£30,400
Receipts per mile	£670	£764
„ per train-mile	4*s.* 8*d.*	4*s.* 8¾*d.*
Expenditure	£11,718	£22,919
„ per mile	£488	£576
„ per train-mile	3*s.* 4¾*d.*	3*s.* 7*d.*
Percentage of expenditure to receipts .	72·78	75·39

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[1] *ide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 240. [2] *Ibid* p. 375.

The details of the expenditure per train-mile are as under:

	d.	d.
Maintenance	11·94	10·79
Locomotive	14·17	18·93
Carriage and wagon repairs	3·69	3·55
Traffic	8·78	7·79
Incidental	0·02	0·05
General charges	2·08	1·80
	40·68	42·91

At present the incline is worked under somewhat unfavourable conditions. Two gangs of men and two engines are always kept at work, the railway manager deeming it advisable to have a second engine and a thoroughly trained gang available on any emergency; in consequence the engines and gangs are not nearly fully employed. The total train-mileage performed by the two engines is under 9,000 miles per annum. The following are particulars of the cost of running the Fell engines with the two gangs:—

	d.	
Repairs—Labour	4·18	per train-mile.
Stores	0·81	„
Running—Fuel	30·32	„
Wages	26·68	„
Total	61·99	„

On an average the consumption of fuel amounts to—coke, 43·71 lbs., and coal, 59·77 lbs.; together, 103·48 lbs. per train-mile.

As the average performance of the engines is only about 15 miles a day, excluding Sundays when trains do not run, it will be seen that the incomplete state of the line is a drawback to economical working, a disadvantage which will disappear. The same may be said of the short service from the foot of the incline to Featherston, which is performed at a proportionately high rate, and which tends to unduly raise locomotive train-mileage charges.

The daily rates of wages on the line are, drivers, 12*s.*; stokers, 9*s.*; cleaners, 7*s.*; fitters, 12*s.*; labourers, 7*s.* to 8*s.* Coal costs 38*s.* per ton in the truck at Wellington, and coke 78*s.* per ton. During the nine months that the incline has been worked, 14,400 tons of goods and 17,700 passengers were conveyed over it both ways, the traffic up and down being nearly equal. The time allowed on the time-table between the summit and the lower station, a dis-

tance of 3 miles 10 chains, is, up thirty-five minutes, down thirty minutes. The running is generally done in less time.

When the Fell engines first started working, accidents arose from the cogs of the spur wheels, which gear together the horizontal driving wheels, fouling and breaking. This appeared serious, and it occasioned the railway manager, Mr. Ashcroft, some anxiety. The cause was, however, traced to the bending of a light bolt, connected with the bearings of the spindles on which the horizontal driving wheels work, being subject to compression, leading it to bulge laterally. When this was remedied no further accident occurred, and the engines have now been running for more than twelve months without a hitch.

In considering the relative advantages of a short incline with a steep gradient, concentrating the heavy work of construction and of traffic within short limits, or of a longer and flatter incline, the chief points demanding attention are:—

1st. The cost of construction.

2nd. The time taken in performing the journey.

3rd. The cost of working.

1st. The economy in construction is, as has been stated, a probable saving in interest of £5,000 per annum by the adoption of the Fell incline.

2nd. By the time-table fifty-five minutes are allowed between the summit and the Featherston station, a distance of 11½ miles. An hour and twenty minutes on the alternative line of 16½ miles would be as short a time as could safely be reckoned upon with an incline of 1 in 40 and 3-chain curves for 8½ miles; indeed an average speed of 12½ miles an hour could scarcely be maintained with safety. A gain in time of not less than twenty-five minutes may therefore be held to have been obtained by the present line.

3rd. The results attained go to show that the system is successful as regards the cost of working. The Author regrets that statistical information of a more detailed and extended nature is not available. It is a matter of surmise only what the cost of working a line with 3-chain curves and upon a gradient of 1 in 40 would be; and as the Author is unacquainted with any line presenting such unfavourable features it would be superfluous to attempt a comparison. Such a line would, equally with the Fell system, require special stock to work it, and the effect of the running on the ordinary stock of the line would be to materially increase the rate of maintenance. The cost of working the line as a whole must be taken, in order to observe the effect of the incline

as regards expenses, as the heavy work is concentrated thereon to the relief of the other portions. At some future date it is hoped that additional information of the cost of working may be laid before the Institution.

The average cost of the line from Wellington to Featherston, including all equipment, has been about £11,400 per mile. The cost of the 3 miles 10 chains, including the incline of 1 in 15 and the shunting stations with the special stock, has been about £88,000, or £28,160 per mile. Unskilled labourers employed on the construction obtained 9*s*. to 10*s*. per day of eight hours; carpenters from 10*s*. to 12*s*. The average cost of the rails delivered in Wellington was £15 per ton, they as well as the stock having been obtained when the home markets were exceptionally dear. Looking to the high rates paid for stock, permanent way and labour, and the difficult country, the average cost must be considered low.

Messrs. C. B. Knorpp, M. Inst. C.E., superintending engineer, North Island, W. P. Hales, W. K. Mason and G. M. Wink, resident engineers, were the principal officers in charge of the construction.

Part II. NAPIER TO MANAWATU (Plate 4).

The Napier-Manawatu Railway, part of the main line projected between Wellington and Napier in the North Island of New Zealand, was explored and commenced under the superintendence of Mr. Carruthers.

Napier is a port on the east coast having a bar-harbour accessible to coasting craft and small steamers. The country to the south for 60 miles is to a large extent an alluvial shingle plain formed by the Tutaekuri, Ngaruroro and Tukituki rivers, which drain the eastern slopes of the Ruahine and Kaimanawa plateaux. The line rises gradually with gradients not exceeding 1 in 49 on the straight towards the summit at about 75 miles from Napier, where it attains a height of 1,060 feet above the sea; for the first 64 miles it passes over an open country devoted almost entirely to pastoral pursuits. The rivers on this part are shingle-carrying streams of considerable magnitude, and liable to floods, during which they spread over large areas of country, their banks being ill-defined or almost absent. About the 64th mile the line enters upon a broken, densely bushed country on another watershed. The Manawatu river rises on the south-eastern slopes of the Ruahine range, and passing southwards, receives the drainage of a large area of the east coast ranges. It enters the

Manawatu gorge between the Tararua and Ruahine ranges at about 100 miles from Napier; at the crossing of the line it is a small stream; but at the gorge it is a large river having a rise in extreme floods of 58 feet.

The nature of the geological formation, which is composed of marine beds of a dense clay rock, locally termed "papu," interspersed with sand and shell beds much distorted and faulty, has led to the erosion of deep ravines by the Manawatu and other small tributary streams. Gullies, frequently over 100 feet deep, are met with, formed by the local flood drainage only; and extensive landslips are often found, due to the water-bearing strata of sand intermediate in the clay beds.

The Papatu section of the line is about 5 miles long; it includes the crossings of three ravines, the Manawatu, the Mangarangiora and the Makatoko. Considerable difficulty was experienced in finding suitable crossing places. No building stone was available in the country, and the use of iron would have been costly and have involved serious delay; on the other hand the local bush contains timber of excellent quality suitable for bridge building. These facts led the engineer-in-chief to adopt a system of trestle bridging as being the most economical and the most readily executed.

The structures are made for a line of 3 feet 6 inches gauge, and to carry locomotives having a maximum weight of 7 tons on a pair of wheels, and they are equal to a moving load of 1 ton per lineal foot. They are designed for erection without staging; the dimensions of the timbers are fixed to facilitate transit by the rough bush tracks and handling during erection; and they were erected on this system with great facility and rapidity.

The materials chosen were totara, matai, and black maire timbers. Totara and matai were used in the main structure, and maire in the scarf fittings and joggles. Totara is a tree from 6 feet to 10 feet in diameter, attaining a height of 70 feet; and is the most durable of New Zealand timbers. It is useful in marine works, resisting the teredo longer than any other colonial wood. The Maoris employ it for making their dug-out canoes and their huts; it grows extensively in both islands, and piles of 40 feet in length have been obtained, and used on the public works of the colony. Matai is stronger than totara, but less durable. Black maire is a dense, tough timber, very useful for scarfing, thrust blocks, and similar descriptions of work; it is not easily obtained in long lengths. The lower chord of the 51-feet girder span was specified to be of black maire, but from the difficulty in obtaining

it the contractors were allowed to use iron bark from Australia. Some particulars of these timbers are given in Appendix II. Where the strata did not admit of piles being driven, bases of Portland cement concrete were used.

Plate 5 illustrates the design of all the bridges, being a representation of that prepared for the crossing of the Mangarangiora ravine. Some changes were made in executing the foundations, necessitated by the peculiarities in the strata; the concrete bases being extended, and the piles somewhat altered.

The principal difficulties in execution arose from the situation of the works in a rough bush-covered country without roads or tracks, for wet weather renders the bush tracks impassable, even to bullock teams. During winter little or no work could be done, and some delay arose through an exceptionally wet summer in 1878–9. The time occupied on the work was two years.

The following are particulars relating to these bridges:

Bridge.	Greatest Height.	Length.	Area in 100 Sq. Feet.	Total Cost.	Cost per 100 Sq. Ft.	Cost per Lineal Ft.
	Feet.	Feet.		£.	£.	£.
Manawatu . . .	89	484	267	5,799	21·71	11·98
Mangarangiora . .	86	606	356	8,412	23·63	13·86
Makatoko. . . .	76	224	106	3,049	28·75	13·60

The cost given above includes a proportion for engineering and office expenses. The works were let by public tender to Messrs. Proudfoot and Mackay, of Dunedin; the workmanship is exceptionally good. The simplicity and cheapness of this class of structure especially recommend it to notice. In Appendix II. will be found the quantities of materials used, and the prices. The rates for the timber and ironwork were considered low for colonial practice.

The work was performed under the Public Works Department of New Zealand, Mr. Carruthers being engineer-in-chief, and Mr. John Blackett assistant engineer-in-chief. It was supervised by Mr. C. B. Knorpp, superintending engineer, North Island, and by the Author. Mr. J. T. Carr was the resident engineer, and Mr. E. Fulton, assistant engineer.

The Paper is accompanied by several maps and drawings, from which Plates 4 and 5 and 7 (in part) have been prepared.

APPENDIX I.

CURVES from the 19th MILE to the SUMMIT. Length 15 miles.

		Total chains.
Radius	5 chains: 4·20, 4·30, 7·50, 8·10, 3·50, 6·50, 3·10, 7·20, 5·60, 5·45, 1·50, 6·30, 8·20, 1·70, 11·20, 2·60, 3·00, 3·20, 1·50, 4·20, 4·30, 6·10, 11·20, 7·60, 2·40, 3·50, 3·10, 10·20, 5·50, 8·25, 4·40, 3·50, 4·40, 5·90, 7·10, 7·20, 5·90, 6·40, 3·30, 3·60, 5·60, 2·50, 2·50, 0·60, 4·00, 5·10, 9·70, 3·90, 7·10, 5·00, 7·80, 2·40, 3·20, 7·15, 4·65, 9·50 .. .. =	293·40
„	6 chains: 3·50, 1·65, 2·10, 2·90, 4·60, 2·80, 0·30, 1·65, 8·10 4·00, 3·10, 2·50, 3·60, 3·60, 1·60, 1·40, 11·20 .. =	58·60
„	7 chains: 10·20, 3·50, 3·90, 3·70, 2·60, 4·40, 2·20, 3·70, 4·00, 7·00 .. .. =	45·20
„	8 chains: 0·70, 6·70, 4·95, 2·00, 4·40, 2·60, 6·70, 3·10, 4·90.. .. .. =	36·05
„	9 chains: 4·0, 4·0 .. .. =	8·00
„	10 chains and upwards: 10·00, 2·80, 12·30, 3·30, 4·25, 4·30, 2·60, 8·50, 7·00, 10·35, 3·40, 3·00, 7·90, 1·15, 1·20, 1·10, 6·30 .. .. =	89·45
	6 miles 50·70 chains =	530·70

CURVES on the $\frac{1}{15}$ GRADIENT. Length 2 miles 45 chains.

		Total chains.
Radius	5 chains: 1·40, 2·10, 1·35, 5·65, 2·15, 0·40, 3·30, 12·45, 3·20, 1·00, 6·30, 10·40, 6·70, 5·45, 6·35, 4·90, 1·10, 3·90, 1·50, 2·75, 1·50, 0·50, 6·65, 4·90, 5·00, 1·50 .. .. =	102·40
„	7 chains: 3·65, 7·10 .. .. =	10·75
„	10 chains and upwards: 5·55, 4·45 .. .. .. =	10·00
	1 mile 43·15 chains =	123·15

CURVES from the $\frac{1}{15}$ GRADIENT to the 41st MILE. Length 2 miles 35 chains.

		Total chains.
Radius	6 chains: 4·05 .. .. =	4·05
„	7 chains: 4·10, 2·60, 3·05 .. .. =	9·75
„	10 chains and upwards: 1·40, 2·50, 14·40, 7·35, 8·80, 6·95 =	41·40
		55·20

APPENDIX II.

I. PARTICULARS of TIMBERS USED for the PAPATU BRIDGE, from the EXPERIMEN of the LATE J. M. BALFOUR, M. Inst. C.E. [*Vide* New Zealand Exhibiti 1865; being Appendix C. of the Jurors' Reports. Inst. C.E. Tract 8 vol. 155.]

(*Mean Results.*)

Timber.	Specific Gravity.	Weight per Cubic Foot.	Breaking Weight in lbs. a beam 12 inches lo by 1 inch square, su ported at both ends a loaded in the middle.
		lbs.	
Totara (*podocarpus totara*) . .	0·559	35·17	534
Matai (*podocarpus spicata*) . .	0·658	40·74	760
Maire (*olea apetala*)	1·159	72·29	1,256
New South Wales Iron Bark .	1·138	70·92	1,128

II.—QUANTITIES in the WORKS as EXECUTED and PRICES.

			s.	d.	£.	s.	d.
Timber . .	536,518 B.M.	@	32	0	8,584	0	8
Piling . . .	21,105 lineal feet	„	4	8	4,924	8	0
Wrought iron .	84,900 lbs.	„	0	5	1,768	15	0
Concrete . .	352 cubic yards	„	50	0	880	0	0
Ballast . .	628 „ „	„	8	0	251	4	0
Excavation .	2,800 „ „	„	2	6	350	0	0
					16,758	7	8
Engineering and office					502	0	0
					£17,260	7	8

(*Paper No. 1720.*)

"Ceylon Government Railways."[1]

By JAMES ROBERT MOSSE, M. Inst. C.E.

THE object of this Paper is to give a brief account of the Ceylon Government Railways as opened for traffic, and of the extensions surveyed and partly under contract.

PART I.—LINES OPENED FOR TRAFFIC.

Main Line, Colombo to Kandy; length, 74½ miles.—In the year 1847 a company was formed for the construction of a railway from Colombo to Kandy. The first survey for the line was made for the company by Mr. T. Drane, M. Inst. C.E. But it was not until 1856 that a provisional agreement was made, under which the Government guaranteed to the company interest at the rate of £6 per cent. per annum on a capital not exceeding £800,000, and of £5 per cent. on all capital expended beyond that amount. In the following year the late Captain W. S. Moorsom, M. Inst. C.E., was sent by the Secretary of State to Ceylon to examine the country on behalf of the Government. On the receipt of Captain Moorsom's report[2] the concession to the company was ratified, and at the end of 1857 the late Mr. W. T. Doyne, M. Inst. C.E., was appointed chief resident engineer in Ceylon. In consequence of the great difference in the estimated cost of the line by these gentlemen, the question was in 1859 referred, first to the late Mr. Robert Stephenson, Past President Inst. C.E., and after his death to Sir John (then Mr.) Hawkshaw, Past President Inst. C.E., who reported thereon in June 1860. Meanwhile Mr. G. L. Molesworth, M. Inst. C.E., then acting as the company's agent and chief resident engineer in Ceylon in succession to Mr. Doyne, commenced to survey a new route, which showed a large saving in distance and in cost of works as compared with the surveys previously made. Towards the close of 1861 the contract between the company and the Government was dissolved. At that date the expenditure of the company, including surveys and administration extending over several years, had reached £368,275, of which the land,

[1] The discussion upon this Paper was taken in conjunction with that upon the New Zealand Government Railways.

[2] *Vide* "Report on the Ceylon Government Railway Survey." London, 1857. Inst. C.E. Tract, folio, vol. 10.

works, and stores handed over to the Government were of th estimated value of £125,000. In February 1863 a contract wa entered into by the Government with Mr. W. F. Faviell, Asso Inst. C.E., for the construction, on Mr. Molesworth's plans, of th railway from Colombo to Kandy, and it was opened for traffic o the 1st of August, 1867. When Mr. Molesworth was appointed i 1867 the Director of Public Works in Ceylon, Mr. Devonsher Scott, M. Inst. C.E., succeeded him. The late Mr. James Meadow Rendel, Past President Inst. C.E., was the consulting engineer the company until his death in 1856. He was succeeded b Mr. Charles Hutton Gregory, C.M.G., Past President Inst. C.E who since 1861 has acted in the same capacity for the Governmen and the engineering works of the Ceylon railway have been carrie out under his general direction.

From Colombo to Rambukkana, a distance of 52¼ miles, the lin passes generally through a country with gradients not exceedin 1 in 100, and curves of not less than 20 chains radius, with a fe exceptional curves of 10 chains. The Kadugannawa incline, continuous gradient of 1 in 45, commences at 52¼ miles fro Colombo, and extends for 12 miles, the rise being 1,408 fee Kadugannawa station, the summit of this part of the line, 1,618 feet above the sea. The incline is carried along the side a precipitous range of mountains, involving ten tunnels with large quantity of rock cutting, the entire length being a successio of reverse curves of 10 chains radius, varying in direction eve few hundred yards. The iron rails originally laid on the inclin rapidly wore out, and within three years they were replaced b steel rails; these latter have not been found appreciably to affe the adhesion of the driving wheels of the locomotives; still damp weather the use of sand is necessary.

For the 10 miles from Kadugannawa to Kandy the line chief follows the valley of a river, which renders necessary the use curves of 10 chains radius, although the works are not of a heav character.

	Rs.	Rs.	
On the 1st of January, 1868, the capital account was closed, and the total cost was found to be	17,384,832	or 233,354	per mile
From that date to the 31st of December, 1878, there have been expended on new works defrayed entirely from current revenue	677,080 „	9,088	„
Totals	18,061,912 „	242,442	„

Nawalapitiya Branch; length 17 *miles.*—This branch, leaving Peradeniya at 70½ miles from Colombo, passes through Gampola, and terminates at Nawalapitiya at a level of 1,913 feet above the sea. The ruling curve is 10 chains radius, and the maximum gradient from Peradeniya to Gampola, 7¾ miles, is 1 in 70; between Gampola and Nawalapitiya it is 1 in 50 for a continuous length of 2 miles. The country is somewhat rough, and the works are on the average heavier than those on the main line, the Kadugannawa incline being excepted.

In September 1871 a contract for the construction of this branch was entered into with Messrs. Reid and Mitchell, and the line was opened for traffic on the 21st of December, 1874. Up to the end of 1877 the total cost of construction had amounted to Rs. 2,841,497, equal to Rs.167,147 per mile. These works were designed and carried out by Mr. E. Strong, M. Inst. C.E.

Kalutara Railway; length, 27⅝ *miles.*—The railway from Colombo towards Galle was opened for traffic to Moratuwa, 13¼ miles from Colombo, on the 1st of March, 1877, and to Panadure, a further distance of 4 miles, on the 1st of September of that year. It was subsequently extended and opened to its present terminus in the town of Kalutara at the end of September, 1879.

Following the seashore, this railway is chiefly a surface line, and with the exception of two large bridges, there are no heavy works. The Panadure bridge has ten spans of lattice girders, each 60 feet in the clear; each pier consists of two cast-iron cylinders, 5 feet in diameter, filled with concrete. The Kalutara bridge, designed and built by the Author as Director of the Public Works Department in Ceylon, is the longest structure in the colony. It consists of two bridges, each containing six spans of lattice girders 100 feet in the clear, separated by an island in the middle of the river, upon which an embankment is raised. There are therefore four brick abutments and ten piers, each pier being formed of two cast-iron cylinders, each 6 feet in diameter, shipped in segments of three to the circle and 6 feet in height. The iron-work consists of strong single-lattice girders, having a flooring of corrugated iron, on which is laid cement concrete 6 inches thick. The preliminary borings having shown that a bed of gravel existed at about 30 feet below ordinary water-level, no pneumatic process was deemed necessary for the work, the excavation being performed by the ordinary methods with the assistance in deep water of divers. The cylinders were weighted in the usual manner, and when sunk to the rock they were fitted to the bed-plates with cement concrete.

After reaching the gravel, which unfortunately proved to be only about 2 feet in thickness, the cylinders were sunk through a bed of soft sand, until the solid rock was reached, at depths of from 50 to 70 feet below the ordinary water-level. This entailed great delay and expense, but in view of the numerous failures from the underscouring of bridges in India, the Author did not feel justified in subjecting the Government to the risk which a less secure foundation would have involved. One of the abutments was on rock; the other three were founded on piles driven 3 feet apart from centre to centre, the intermediate spaces being filled with cement concrete; on the piles large longitudinal pieces were laid, upon which cross planking, 3 inches thick, was spiked, and on this planking the abutments were built of brickwork in cement. The abutments were encased by sheet piling (subsequently cut off at high water), and cement concrete was rammed between the brickwork and piling.

The following appliances were tried in the excavation of these abutments and piers:—An improved scoop or jham worked by tackle; the ordinary sand pump; Bull's dredger; Molesworth's dredger; Ives's excavator; Stoney's helical excavator. Of these the last was the most effectual, although at great depths it required strong vertical rods and a good deal of manual labour to work it. Had the Kalutara bridge been a larger work, and had it been known that the foundations would have proved so deep, more effectual appliances might have been used in the first instance; but as the anticipated depth of foundation was only 40 feet, and the length 1,200 feet, it did not seem advisable to import costly apparatus, especially as the more complicated the appliances the more difficult it would have been to work them with the Sinhalese and Tamil labour available. This bridge, designed and opened in August 1877 for the turnpike road traffic from Colombo to Galle, included provision for the single line of rails which is now laid in the middle of it. The total length of the Kalutara bridge, with about 450 feet of embankment on the island, is 1,800 feet, and the total cost was Rs. 624,000, or Rs. 347 per lineal foot.

The total cost of the works on the Kalutara railway, designed and carried out by Mr. E. Strong, has been Rs. 2,150,139, equal to Rs. 77,833 per mile.

The chief particulars of the permanent way on the main line and branches are as follow:—The line is single, having a gauge of 5 feet 6 inches. Flange rails weighing 72 lbs. per yard, and 21 feet in length, are employed; at first these were of iron, but

steel rails are used for renewals. The sleepers are on an average 2 feet 7½ inches apart, that is, there are eight sleepers in a length of 21 feet; they are chiefly of creosoted Baltic fir, 9 feet long by 10 inches wide by 5 inches thick, and two intermediate sleepers. The joint sleepers and two intermediate ones are of native hard wood, to which the rails are fastened by two fang-bolts; in the other cases square dog spikes are used. The traffic on the railway from Colombo to Kalutara is of a lighter description than on the other lines, consisting chiefly of passengers, and the rails are 60 lbs. instead of 72 lbs. to the yard.

Revenue and Working Main Line, Colombo to Kandy, 74½ miles.—Before alluding to the financial success of this railway, it will be well to describe briefly the Kadugannawa incline and its working. The line passes along the side of a precipitous mountain range, somewhat similar to the Bhore Ghaut in the Bombay Presidency, with numerous projecting spurs and deep ravines. The best type of ordinary goods engine in use has inside cylinders 16 inches in diameter, with a stroke of 22 inches; the heating surface of the boiler is 907 square feet, and of the fire-box 102 square feet, total 1,009 square feet. The driving wheels are 5 feet in diameter, four wheels coupled; the length of the wheel base is 8 feet. The centre of a four-wheeled bogie, of which the wheels are 3 feet in diameter, is placed under the centre of the smoke-box, and is fitted with lateral movement. The weight of the engine in steam is 35 tons. The tender has six wheels 3 feet 6 inches in diameter, with brake blocks on each wheel; the tank is flat-topped, holding 1,500 gallons.

The bank engines, exclusively employed in working at slow speed the Kadugannawa incline, are of the following dimensions:—The driving wheels are 4 feet 5 inches in diameter; all six wheels are coupled. The length of the fixed wheel base is 9 feet 6 inches. The outside cylinders are 17 inches in diameter; the length of stroke is 26 inches. The heating surface of the boiler is 1,225 square feet, and of the fire-box 117 square feet, total 1,342 square feet. The weight of the engine available for adhesion is 32½ tons. The tender is on wheels 3 feet 6 inches in diameter. The tank is flat-topped, with a capacity of 1,500 gallons. All the locomotives have steel tires. The engine-drivers of trains are Europeans, the drivers of shunting engines are natives. Wood is largely used as fuel, and 10 cubic yards of wood, costing Rs. 15, are found to be equivalent to 1 ton of coal costing Rs. 23. Working at their full power, the bank engines consume 1 cwt. of coal per mile, and evaporate 1,400 gallons of water in the ascent of 12 miles. The

wheel base of the carriages is 9 feet 6 inches, and that of the wagons is 8 feet.

The Kadugannawa incline is thus worked:—All ascending passenger trains have an assisting engine in the rear. When the load does not exceed sixteen vehicles the train engine is in front, an assisting locomotive of the goods class being behind; when the load exceeds this number, a bank engine is placed in front of the train, and the train engine in the rear. In descending the incline no additional brake vans are attached to the train, but every passenger vehicle (except the first-class carriages) is fitted with an independent self-acting spring brake; these brakes are tightened by the guards before commencing the descent, and require no further attention. Trains of from fifteen to thirty carriages fitted with these brakes have for several years descended the incline with safety and regularity.

The goods trains are composed of twenty-four loaded wagons of about 11 tons each, and one brake-van from Colombo to the foot of the incline, where six wagons are shunted, and the train is made up of eighteen loaded wagons and two brakes. The bank engine, whose duty it is to haul twelve wagons and one brake-van, is then attached to the front of the train, and the train engine placed in the rear of the train should propel the remaining six wagons and the other brake-van. In descending the incline, one heavy brake-van, in addition to the ordinary train brake-van, is placed in the centre of the train; a weight of 50 lbs. is also hung to the end of all brake levers of the wagons. These sufficiently retard the speed of the train, the brake-van and tender brakes being usually held in reserve for emergencies and for stopping the trains. The goods trains in descending are limited to twenty-four loaded wagons and two brake-vans. Two and sometimes three locomotives are attached to the front of the train and this practice is not found to produce the jars or shocks which might be anticipated. The incline is traversed by from twelve to fourteen trains daily, with "specials" when required; and although the incline has been thus worked for more than twelve years, the Author believes that no accident involving injury to any passenger has occurred.

The incline is worked by the staff, and on the block system from three telegraph stations, averaging 4 miles apart. The staff system is used on the other portions of the main line and branches the trains being signalled by telegraph from the principal stations. Both passenger and goods trains, whether on the ascent or descent of this incline, are limited to a speed of 12 miles per hour.

A summary of the receipts and expenses, &c., for each of the ten years from 1869–1878 both inclusive, is given in the Appendix, Table I.

The average of these figures is as follows :—

Receipts per annum	Rs.	2,335,667
Expenses	„	812,824
Net profit	„	1,522,843
Percentage of profits to capital . . .		8·76
Number of passengers		772,422
Tonnage of goods		176,807
Train-miles run		298,448
Receipts per mile of line open . . .	Rs.	31,347
Receipts per train-mile	„	7·80
Expenses „	„	2·75
„ per cent. of receipts . . .		35·20

In 1869, seventeen months after the railway was opened for traffic, the percentage of profits to capital was 6·2; for the last ten years it has averaged 8·76, and for the last four years 10·85. Considering that the traffic is in every respect liberally worked, and at low rates both for passengers and goods, the financial success of the line is very satisfactory; and the indirect benefits of railway communication in developing the resources of the colony fully justify the Government in continuing the same policy as regards the railway extensions now in hand.

The particulars of the working expenses of the railway from Colombo to Kandy for the three years 1876, 1877, and 1878, are given in the Appendix, Table II. The average for the three years is, percentage of receipts, 32·1; cost per mile open, Rs. 12,210; cost per train-mile, Rs. 2·48.

Nawalapitiya Branch, 17 miles.—The receipts and working expenses of the Nawalapitiya branch railway from the opening in 1873 to the end of 1878 are given in the Appendix, Table III.

The average of these figures for the six years ending 1878 is as under :—

Receipts	Rs.	288,367
Working expenses	„	145,760
Net profit per annum	„	142,607
Percentage of profit to capital		6·62
Miles of line open, average		14·0
Number of passengers	Included in return of line from Colombo to Kandy.	
Tons of goods		
Train-miles run		60,804
Receipts per mile of line open	Rs.	19,884
„ per train-mile	„	4·97
Expenses „	„	2·43
„ per cent. of receipts		49·0

The particulars of the working expenses on the Nawalapitiya branch for the last three years, are given in the Appendix, Table IV.

The average for the three years 1876, 1877, and 1878, is, per-centage of receipts, 51·3; cost per mile open, Rs. 11,536; cost per train-mile, Rs. 2·34, = 4*s.* 1*d.*

Working of the Kalutara Railway.—This line was opened to Moratuwa, 13¼ miles, on the 1st of March, 1877, and has been since extended to Kalutara by small sections at different dates. The traffic has hitherto been exclusively passenger, and the few months which have elapsed since the opening of the line have not sufficed for any development of the resources of the district; the average profit in 1877–78 on the capital expended on this line has been at the rate of 5 per cent. per annum.

General Summary.—From the official reports the cost of construction appears to have been as follows:—

	Rs.	Per Mile. Rs.
Main line, Colombo to Kandy .	18,061,910	= 242,442
Colombo wharf line	28,351	
Nawalapitiya branch	2,841,497	= 157,331
Kalutara railway	1,913,690	
Total	22,845,448	

The statement of receipts and expenditure, and of the revenue for 1878 of the above lines (Appendix, Table V.), shows that after providing out of revenue Rs. 267,570 for additional accommodation and new works, there remained a profit of Rs. 1,828,872.

The capital expenditure on the whole of the open portions of the Ceylon railways at the end of 1878 had been Rs. 21,212,771, and the profit on the working for that year was at the rate of 9·1 per cent.

Owing to the decrease in the coffee crop, the receipts in 1878 were much less than in the preceding year, and the extraordinary rain during the whole of July 1878 seriously damaged the line and added greatly to the working expenses. From the year 1876 to 1878 inclusive, the annual net receipts on the Ceylon Government railways have averaged Rs. 2,155,990, equal to a profit of 9·93 per cent. per annum. Of the capital alluded to the Government owe only £350,000, due in the years 1882–83, on the debentures issued for the railway from Colombo to Kandy, towards the payment of which the Government have already invested £246,500 in the hands of Trustees, thus leaving of the entire capital, say

£1,856,000, only £103,500 unredeemed. For the construction of the Nawalapitiya branch, debentures to the extent of Rs. 400,000, issued in Ceylon in 1872, were repaid in December 1877, the cost being ultimately defrayed from the general revenue of the colony. Similarly the cost of the Kalutara railway up to the end of 1878 has been paid out of the surplus and general revenue of Ceylon, Rs. 2,000,000 having been voted for that work.

Between 1875 and 1877 the extension from Kandy to Matale, about 17½ miles in length, was surveyed for contract. These works were, in May 1878, let to Mr. David Reid, Assoc. Inst. C.E., whose tender, for works only, amounted to Rs. 1,782,408. The permanent way, the ironwork for bridges, the stations and the rolling stock, none of which are included in Mr. Reid's contract, are provided by the Government. The total estimated cost of the Matale extension amounts to Rs. 3,300,000, being at the rate of Rs. 189,247 per mile. This line was opened for traffic on the 4th of October, 1880.

Part II.—Lines under Construction.

Ceylon Railway Extension to Uva.—The town of Nawalapitiya, at the level of 1,913 feet above the sea, is situated at the lower end of two large valleys, one valley leading to the extensive coffee districts of Kotmalie, Dimbula, Lindula, and the Agra-Patanas; the other to Dikoya and Maskeliya. These districts, at a height from 3,000 to 5,000 feet above the sea, embrace about 86,000 acres of coffee cultivation, and include some of the best estates in Ceylon.

Nawalapitiya, being situated at the foot of the steep rise to the "up country," was for some time considered to be the natural and final terminus of the railway, especially as good cart roads lead from it to the surrounding districts. These roads, winding round numerous spurs and valleys, require an unusual amount of waterway; they are substantially built and well metalled; the dry stone retaining walls and culverts built by the "pioneers," a Government force of about thirteen hundred trained masons, stonecutters, and builders, are of very superior work, and the bridges generally of dressed masonry have either an ashlar arch, or iron girders and corrugated flooring.

The inclination of the roads on the passes generally varies from 1 in 20 to 1 in 30, the limit on those recently constructed being, whenever practicable, 1 in 25, and where zigzags are indispensable the road is made level for a length of 100 feet round the turn.

From want of funds the old roads were made too narrow, the

road-bed being only 16 feet wide, having a width of 14 feet foundation or "bottoming" on Telford's system, and a depth 6 inches of broken stone. The roads are frequently carried to far round the heads of ravines, but admitting that to obtain lengt for a maximum gradient this detour may sometimes have bee necessary, it has more frequently been made solely with a view t economy, although the result is practically a loss.

The cost of constructing cart roads "up country" in the hill district of the central province is about Rs. 25,000 per mile, exclusive of large bridges, and the cost of their repair usually varie from Rs. 1,200 to Rs. 2,800 per mile per annum. This apparently excessive expenditure is easily accounted for; the loaded carts, which often weigh from 2 to 2½ tons, carry about 1 ton on each wheel, the tires being only 2½ inches wide. The carts generally travel close together in sets of from six to twenty in the same track. The bullocks are overloaded; they stop frequently, and on starting, being unable to move the carts in a straight line, wriggle about with a zigzag motion, which soon makes holes in the road, and thus a depth of 3 inches of metal and gravel, costing about Rs. 2,000 per mile, is often worn down in a year. When to this is added the expense of removing landslips, the repairs of bridges, and the casualties due to a rainfall of about 150 inches per annum, the high cost of repairs is easily accounted for.

Assuming the maintenance of a road, called in Ceylon "the upkeep," to be Rs. 2,000 per mile per annum, this sum, capitalized at 5 per cent., is equal to Rs. 40,000; so that an expenditure of Rs. 10,000 in saving ¼ mile of road would be judicious, irrespective of the saving of time to travellers, and of the wear and tear of horses and vehicles. It is interesting to record that previous to the opening of the railway from Colombo to Kandy, the maintenance of this cart road, from 1863 to 1865 inclusive, averaged £460 per mile per annum, and that generally the tolls somewhat exceeded the cost of repairs.

Provisions, rice, manure, and all articles required for "up country," are still conveyed from Nawalapitiya in bullock carts weighing about ½ ton, and carrying 1 ton or more as an up-load, and from 1½ ton to 2 tons as a down-load. They travel on an average only 6 miles per day, and the cost of cartage is from 1*s.* 8*d.* to 2*s.* 6*d.* per ton per mile.

The necessity of railway extension beyond Nawalapitiya, therefore, became evident; and in June 1872 the coffee planters addressed a memorial to the Government of Ceylon, requesting that an examination of the country for a railway might be made from

Nawalapitiya through Dimbula and Haputale to Badulla, the centre of the Uva district. In 1873 and 1874 this survey was made by the Surveyor General's Department under the immediate charge of Mr. John Stoddart. The result showed both the feasibility and the difficulty of constructing a railway through an excessively rugged country, of which the lowest summit is about 6,400 feet above the sea. Detailed surveys were made from 1875 to 1878.

The practicability of the railway being evident, contract surveys were ordered by the Ceylon Government, and early in 1875 an engineering staff, selected by the consulting engineer, was sent to the colony under the charge of Mr. Alex. H. Macnair, M. Inst. C.E.

From 1875 to May 1877 surveys, plans, and estimates for contract were made from Nawalapitiya to Nanu Oya, a distance of 41 miles 26 chains, but with the exception of about 6 miles the lines then surveyed were subsequently abandoned. A preliminary survey from Haputale to Ella, a distance of about 15 miles, was also made.

On the resignation of Mr. Macnair in March 1877, the Author was appointed chief engineer of the railway extension surveys, of which, as a member of the Railway Commission, he had previously acquired some knowledge, and the charge of the works during construction has subsequently been entrusted to him.

The country and survey from Nawalapitiya to Badulla will now be briefly described. The Kadugannawa incline on the main line from Colombo to Kandy being 1 in 45, the consulting engineer decided to adhere to this inclination, although it was subsequently modified to 1 in 44 as a maximum on the Uva extension. The country unfortunately rises so fast that this gradient can only be obtained by seeking additional length with special ground to suit it, and the great difficulty of the survey consisted in finding ground rising for about 20 miles to the summit, and afterwards falling, approximately at 1 in 44, at the same time incurring the least amount of work. The difference in time and labour involved by this process, as compared with surveying a country where the gradients could be suited to the ground, will be readily understood. With the exception of pieces aggregating 1¼ mile in length, the gradient of 1 in 44 prevails for 18½ consecutive miles in ascending from Nawalapitiya to Hatton, and for 12¼ miles in descending from the summit to Haputale; there are also lengths of this gradient for 5½ and 7 miles respectively. A gradient of 1 in 52·8 also prevails for 6½ continuous miles.

The general course of the route is necessarily circuitous, as the railway must be taken to the centres of the coffee districts situated

at Hatton, Talawakela, Nanu Oya, and Haputale, the last bei the most important coffee district in the colony.

At first it may appear strange that the railway on leavi Kandy should rise some 4,600 feet and then descend 4,040 feet befo reaching Badulla, the total rise being about 560 feet only; a that, moreover, the distance by railway should be 115 mile whereas by the old bridle path the distance was only about ha this mileage. But the latter route would be impracticable: firs because it would be chiefly through uncultivated country, a would not touch the centres of traffic for which especially th railway is required; secondly, because the country being ver rugged it would be impossible to obtain a uniform rise from Kand to Badulla without increasing by 50 per cent. the distance by the ol path, or say 84 miles as compared with 115; thirdly, the climat on the shorter route is so unhealthy that much delay, and probabl increased cost in the construction of the works, would ensue.

The "up country" in Ceylon consists of a series of spurs of hills ravines, and large hillocks, having often in a short distance a difference in level of from 500 to 1,000 feet; sharp curves, there fore, became imperative for any railway, the cost of which would not be prohibitory.

In 1875 a discussion took place in Ceylon as to the merits for the Uva extension of a gauge of 3 feet 6 inches as compared with the 5 feet 6 inches gauge of the line from Colombo to Nawalapitiya; the Government wisely determined to adhere to the existing gauge.

The minimum radius, fixed where compulsory at 5 chains or 330 feet, has only been used in twelve cases, the total length being 1 mile 50 chains; and on 71 chains of this distance the gradient has been flattened from 1 in 44 to 1 in 50¾. Where indispensable for economy the radius generally used is 420 feet, and of these curves there are three hundred and seventy-one, having an aggregate length of 27½ miles. This radius was chosen as one on which suitable locomotives with a bogie frame in front can easily work. Every effort to avoid unnecessary curvature has been made. A summary of the alignment is given in Table VI. in the Appendix, and particulars of the gradients in Table VII. The maximum gradient of 1 in 44 prevails for 61 per cent. of the whole distance, and 75 per cent. of the gradients are steeper than 1 in 60. The chief average gradients and their height above the sea are given in the Appendix, Table VIII.

The estimated cost of the railway from Nawalapitiya to Badulla is given in Table IX.

In 1875 ten assistant engineers were selected to undertake the surveys of the railway extension, and the whole staff has not

averaged more than twelve in number. The rugged character of the country, and the necessity of commencing the gradient of 1 in 44 at points about 20 miles distant from the summit to be reached, rendered the progress both difficult and slow; more than two engineers could not advantageously work in one party, it being necessary to keep the theodolite and the level close together, and to maintain the gradient, and to fit appropriate curves to the rough spurs and ravines, without incurring prohibitory works, was found to entail an excessive amount of labour. The following was the usual day's proceedings of a party. About 7 A.M. the two engineers, accompanied by about twenty-five Sinhalese as chainmen, axemen, &c., left their camp, and after walking for about an hour and a half commenced work and continued at it till noon; they then returned to camp and plotted the work done that morning, so as to see how it would fit into that to be done the next day, a system which was found to be indispensable. For long distances the route lay through heavy jungle, where not more than 10 chains of line could be cut or levelled per day; in fact the progress made by each party did not exceed 1 mile per week. This slow rate of progress was owing to the unusual ruggedness of the country, the tropical and unhealthy climate, the excessive rainfall, varying from 150 to 180 inches per annum, the inexperience of the Sinhalese chainmen, and the difficulty of working through an interpreter. About four years were occupied in making the surveys and preparing plans and estimates for 112 miles of railway; but this included setting out and levelling twice nearly the whole distance, and running also the many miles required for the preliminary surveys, besides a large amount of work done at the commencement of the survey with the view of adopting a gauge of 3 feet 6 inches and a free use of curves of 5 chains radius.

The cost of the survey, defrayed from the general revenue of the colony, was approximately Rs. 568,682, equal to nearly 2½ per cent. on the estimated cost of the works; and this is equal to Rs. 5,077, or, say, £445 per mile of line finally adopted.

The construction of the railway from Nawalapitiya to Nanu Oya having been sanctioned by the Secretary of State for the Colonies, tenders were, on the 3rd of November, 1879, invited by public advertisement, and in May 1880 the contract for way and works, including stations (but excluding permanent way materials, iron-work for bridges, telegraph and rolling stock provided by the Government) was let to Messrs. Thomas Nowell and Co. for the sum of Rs. 7,094,169, equal to Rs. 171,668 per mile, or when brought into sterling, at 1*s.* 9*d.* to the rupee, equalled £620,740 as the contract sum, or £15,021 per mile. This sum is about £43,500,

or £1,050 per mile, below the Government engineers' estimate fc the works embraced in the contract. Including the items provide by the Government, as above enumerated, the engineers' estimat for the extension from Nawalapitiya to Nanu Oya amounted t £897,376, or £21,718 per mile. The time allowed for the cor struction of the works is five years, the date fixed for the completion being the 20th of May, 1885.

From about the year 1867 to the present date the design of ne rolling stock, and the construction of additional works on th opened railways, and the maintenance of the way and works, an of the rolling stock, as well as the construction of the Nawalapitiy branch and of the Kalutara railway, have been in the charge Mr. Edward Strong, to whose official reports on the railway opened for traffic the Author is indebted for particulars; and fc the last twelve years the traffic and finance branches have bee under the management of Mr. E. Robinson, to whom the Author similarly indebted for the statistics relating to those department

The Governors of Ceylon, during the period referred to in th Paper, have been Sir Henry Ward, Sir Charles MacCarthy, S Hercules Robinson, Sir William Gregory, and Sir James Longder who have given their cordial support to the establishment of the railways.

The railway extension staff in Ceylon includes the followin gentlemen connected with the Institution of Civil Engineers:- Members: Mr. J. R. Mosse, the Chief Resident Engineer; Messr W. G. Ferrar, F. J. Waring, and C. J. Albrecht, Senior Distric Engineers. Associate Members: Messrs. P. R. Emmott, Freder Stafford, and Henry Oliver, Junior District Engineers.

The entire home administration of these railways has been cor ducted, under the orders of the Secretary of State, by the Crow Agents for the Colonies. The engineering arrangements hav been in charge of Mr. C. E. Hollingsworth, M. Inst. C.E. Sinc the early part of 1874 the designs and details of all the iron bridge have been worked out by Mr. G. L. Eyles, M. Inst. C.E. Th principal inspecting engineers for work executed in this countr have been Mr. W. P. Marshall, M. Inst. C.E., for rolling stock and Mr. H. Wakefield, M. Inst. C.E., and Mr. W. H. Stanger Assoc. M. Inst. C.E., for iron bridges, permanent way, and statio equipments.

The Paper is accompanied by several drawings and maps, fror which Plates 6 and 7 have been prepared.

APPENDIX.

TABLE I.—RECEIPTS and WORKING EXPENSES of RAILWAY BETWEEN COLOMBO and KANDY.

	1869.[1]	1870.	1871.	1872.	1873.
Receipts.	Rs.	Rs.	Rs.	Rs.	Rs.
Passengers, parcels, carriages, &c.	367,575	413,765	414,041	405,734	515,143
Merchandise and live stock .	1,417,875	1,630,265	1,561,029	1,439,884	1,723,118
Miscellaneous	24,199	22,372	20,979	21,873	23,465
Totals	1,809,649	2,066,402	1,996,049	1,867,491	2,261,726
Working Expenses.					
Maintenance	260,616	259,541	260,777	251,772	279,778
Locomotive power	243,182	258,270	262,784	277,603	319,699
Repairs of carriages and wagons	53,101	55,794	60,495	49,036	72,119
Traffic charges	104,948	104,473	102,576	105,688	108,301
Police charges	17,340	16,057	16,509	16,317	16,479
Electric telegraph charges . .	10,686	9,916	9,272	10,387	8,487
General charges	35,127	31,414	30,301	27,276	30,614
Totals	725,000	735,465	742,714	738,089	835,487
Net profit per annum . . .	1,084,649	1,330,937	1,253,335	1,129,402	1,426,239
Percentage of profits to capital.	6·2	7·7	7·2	6·5	8·2
Miles of lines open (average) .	74½	74½	74½	74½	74½
Number of passengers . . .	201,258	223,121	234,978	358,651	644,374
Tonnage of goods	134,369	156,205	149,033	138,429	171,193
Train-miles run	245,464	252,305	251,921	237,997	287,510
	Rs. Cts.	Rs. Cts.	Rs. Cts.	Rs. Cts.	Rs. Cts.
Receipts per mile of line open .	24,290 0	27,630 0	26,790 0	25,140 0	30,360 0
Receipts per train-mile . . .	7·37	8·20	7·90	7·86	7·68
Expenses	2·96	2·92	2·96	3·90	2·90
Expenses per cent. of receipts .	40	35½	37	39½	36½

	1874.	1875.	1876.	1877.	1878.
Receipts.	Rs.	Rs.	Rs.	Rs.	Rs.
Passengers, parcels, carriages, &c.	562,664	592,437	649,224	666,844	638,879
Merchandise and live stock. .	1,682,218	1,941,268	1,939,013	2,335,638	2,153,779
Miscellaneous	29,194	37,212	48,820	48,871	29,273
Totals	2,274,076	2,570,917	2,637,057	3,051,353	2,821,931
Working Expenses.					
Maintenance	269,208	241,947	223,905	268,696	284,573
Locomotive power	313,465	318,049	325,767	373,610	375,287
Repairs of carriages and wagons	75,098	67,529	82,602	107,454	92,506
Traffic charges	106,541	112,895	122,535	135,655	146,535
Police charges	16,978	17,190	17,056	18,504	20,804
Electric telegraph charges . .	8,762	11,345	11,228	11,151	13,928
General charges	27,517	35,918	29,285	34,075	33,878
Totals	817,579	804,873	812,378	949,145	967,511
Net profit per annum . . .	1,456,497	1,766,044	1,824,679	2,102,208	1,854,420
Percentage of profits to capital.	8·4	10·2	10·5	12·1	10·66
Miles of lines open (average) .	74½	74½	74½	74½	74½
Number of passengers . . .	708,376	858,094	879,308	1,562,214	2,053,816
Tonnage of goods	167,975	193,239	196,385	237,376	223,867
Train-miles run	294,769	312,256	335,013	378,590	388,661
	Rs. Cts.	Rs. Cts.	Rs. Cts.	Rs. Cts.	Rs. Cts.
Receipts per mile of line open .	30,520 0	34,510 0	35,397 0	40,958 0	37,878 0
Receipts per train-mile . . .	7·58	8·25	7·87	8·60	7·29
Expenses	2·70	2·58	2·42	2·51	2·50
Expenses per cent. of receipts .	36	31·25	30·8	31·1	34·3

[1] For figures of preceding years see Administration Reports of previous years.

NOTES to TABLE I.

Sections of Line when opened for Public Traffic.

1865. Colombo to Ambepussa, 34½ miles open for coaching traffic, 2nd October.
1866. „ „ „ „ goods traffic, 1st January.
„ Ambepussa to Polgahawela, 11 miles open for goods and coaching traffic 1st November.
1867. Polgahawela to Kandy, 29 miles open for coaching traffic, 1st August.
„ „ „ „ „ goods traffic, 1st October.

Expenditure on New Works from Current Revenue, but not included in the Working Expenses.

	Rs.		Rs.
1868	96,650	1875	37,030
1869	151,170	1876	57,641
1870	56,550	„ waterways .	28,776
1871	14,490	1877	77,142
1872	15,610	1878	62,010
1873	8,620	„ waterways .	46,049
1874	1,270	„ rolling stock	159,511

TABLE II. WORKING EXPENSES of the RAILWAY from COLOMBO to KANDY.

	1876.			1877.			1878.		
	Percentage of Receipts.	Cost per Mile open.	Cost per Train-mile.	Percentage of Receipts.	Cost per Mile open.	Cost per Train-mile.	Percentage of Receipts.	Cost per Mile open.	Cost per Train-mile.
		Rs.	Rs.		Rs.	Rs.		Rs.	Rs.
Maintenance . .	8·5	3,005	0·67	8·8	3,607	0·71	10·1	3,820	0·73
Locomotive power .	12·4	4,372	0·97	12·3	5,015	0·99	13·3	5,037	0·97
Repairs of carriages and wagons . .	3·1	1,109	0·25	3·5	1,442	0·28	3·3	1,242	0·24
Traffic charges .	4·6	1,645	0·36	4·4	1,821	0·36	5·2	1,967	0·38
Police „ .	0·7	229	0·05	0·6	248	0·05	0·7	279	0·05
Telegraph „ .	0·4	151	0·03	0·4	150	0·03	0·5	187	0·04
General „ .	1·1	393	0·09	1·1	457	0·09	1·2	455	0·09
Totals . .	30·8	10,904	2·42	31·1	12,740	2·51	34·3	12,987	2·50

TABLE III. RECEIPTS and WORKING EXPENSES of the NAWALAPITIYA BRANCH RAILWAY.

——	1873.	1874.	1875.	1876.	1877.	1878.
Receipts.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.
Passengers, parcels, carriages, &c. . .	59,144	70,826	146,907	158,489	161,981	156,690
Merchandise and live stock	62,218	78,326	161,319	176,483	237,876	240,535
Miscellaneous . .	1,414	2,328	3,500	3,308	6,632	2,223
Totals . . .	122,776	151,480	311,726	338,280	406,489	399,448
Working Expenses.						
Maintenance . . .	17,290	20,200	41,301	45,434	47,659	81,000
Locomotive power .	15,925	17,900	66,722	62,021	78,550	77,836
Repairs of carriages and wagons . .	3,412	3,800	11,774	14,423	17,652	19,230
Traffic charges . .	12,058	20,936	32,929	33,470	34,397	36,346
Police charges . .	2,730	4,399	6,497	6,404	6,676	8,159
Electric telegraph charges	1,365	916	1,694	2,210	1,761	2,141
General charges . .	1,592	1,123	1,633	3,200	4,910	4,879
Totals . . .	54,372	69,274	162,550	167,162	191,605	229,591
Net profit per annum	68,404	82,206	149,176	171,118	214,884	169,857
Percentage of profits to capital . . .	..	..	5¾	6·4	8·0	6·35
Miles of line open (average) . . .	7½	8½	17	17	17	17
Number of passengers	*Included in Return of Line from Colombo to Kandy.*					
Tonnage of goods .			*Do.*			
Train-miles run . .	22,751	25,252	65,414	72,118	88,258	91,036
Receipts per mile of line open . . .	15,840	17,820	18,340	19,899	23,911	23,497
	Rs. Cts.	Rs. Cts.	Rs. Cts.	Rs. Cts.	Rs. Cts.	Rs. Cts.
Receipts per train-mile	5 39	6 0	4 76	4 69	4 61	4 39
Expenses do.	2 39	2 70	2 49	2 32	2 17	2 52
Expenses per cent. of receipts	42¾	45¾	52	49½	47·0	57·5

NOTES.

1873. Peradeniya to Gampola, 7¾ miles open for goods, 15th January.
" " " " " coaching, 1st February.
1874. Gampola to Nawalapitiya, 9½ miles open for goods, 1st December.
" " " " " coaching, 21st December.

TABLE IV. WORKING EXPENSES of the NAWALAPITIYA BRANCH RAILWAY.

	1876.			1877.			1878.		
	Percentage of Receipts.	Cost per Mile open.	Cost per Train-mile.	Percentage of Receipts.	Cost per Mile open.	Cost per Train-mile.	Percentage of Receipts.	Cost per Mile open.	Cost per Train-mile.
		Rs.	Rs.		Rs.	Rs.		Rs.	Rs.
Maintenance . .	13·4	2,673	0·63	11·7	2,803	0·54	20·3	4,764	0·89
Locomotive power .	18·3	3,648	0·86	19·3	4,621	0·89	19·5	4,579	0·86
Repairs of carriages and wagons . .	4·3	848	0·20	4·3	1,038	0·20	4·8	1,131	0·21
Traffic charges .	9·9	1,969	0·46	8·5	2,023	0·39	9·1	2,138	0·40
Police „ .	1·9	377	0·09	1·6	393	0·07	2·1	480	0·09
Telegraph „ .	0·7	130	0·03	0·4	104	0·02	0·5	126	0·02
General „ .	0·9	188	0·05	1·2	289	0·06	1·2	287	0·05
Totals . .	49·4	9,833	2·32	47·0	11,271	2·17	57·5	13,505	2·52

-General Summary of Receipts, Expenditure, &c., of Ceylon Government Railways.

–	Main Line.	Nawalapitiya Branch.	Kalutara Line.	Breakwater Branch.	Wharf Line.	Total.
	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.
s . .	2,821,933	399,449	184,891	36,608	7,583	3,450,464
liture .	967,513	229,593	130,586	20,316	6,012	1,354,021
. . .	1,854,420	169,856	54,305	16,292	1,571	2,096,443
of expen- eceipts .	34·3	57·5	70·6	44·5	79·3	39·3
profits on penditure	10·66	6·35	4·8	..	..	9·1
. . .	386,793	91,036	92,535	13,174	1,868	585,406
	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.
n-mile .	2·50	2·52	1·41	1·54	3·22	2·31

Revenue Account for the Year 1878.

–	Main Line (including Wharf Line).	Nawalapitiya Branch Line.	Kalutara Line.	Breakwater Branch.	Total.
	Rs. Cts.	Rs. Cts.	Rs. Cts.	Rs. Cts.	Rs. Cts.
ce of way, buildings	285,823 16	81,000 0	35,875 10	9,750 0	412,448 26
e charges	377,025 55	77,836 62	41,848 83	3,684 19	500,395 19
carriages . . .	92,916 0	19,230 0	4,813 58	..	116,959 58
rges . .	148,426 57	36,346 43	32,495 2	3,501 67	220,769 69
. .	21,436 49	8,159 56	8,839 99	2,330 47	40,766 49
legraph .	13,928 6	2,141 4	..	..	16,069 10
harges .	33,970 0	4,879 74	6,713 33	1,050 0	46,613 7
					1,354,021 38
accom- . . .	..	..	..	..	22,404 8
	..	..	..	..	245,166 60
s . . .	..	..	..	..	1,828,872 57
e . .	..	..	..	..	3,450,464 63

–	Main Line (including Breakwater and Wharf Lines).	Nawalapitiya Branch Line.	Kalutara Line.	Total.
	Rs. Cts.	Rs. Cts.	Rs. Cts.	Rs. Cts.
s . . .	562,139 35	143,182 64	177,293 7	882,615 6
. . .	..	..	..	16,079 25
. . .	21,862 52	4,532 48	260 50	8,929 75
. . .	..	..	..	1,646 50
. . .	41,211 41	6,775 29	5,559 98	53,546 68
. . .	13,666 66	2,200 0	1,604 13	17,470 79
ise . .	2,149,193 70	238,576 82	..	2,387,770 52
. . .	12,169 17	1,958 58	..	14,127 75
. . .	7,311 88	..	..	7,311 88
e rent .	4,708 74	2,146 65	..	6,855 39
e . .	79 50	..	..	79 50
. . .	17,173 43	76 88	173 25	17,423 56
r materials	36,608 0	..	..	36,608 0
	2,866,124 36	399,449 34	184,890 93	3,450,464 63

TABLE VI.—SUMMARY of the ALIGNMENT, NAWALAPITIYA to BADULLA.

Radius. From Chains.	Radius. To Chains.	Number of Curves.	Total Length in Chains.	Percentage of Total Curvature.
5	6	48	412	9·0
6	7	391	2,363	50·0
7	8	56	318	7·0
8	9	68	362	7·5
9	10	49	258	5·25
10	15	121	738	15·0
15	20	29	168	3·5
20	30	12	78	1·75
30	60	6	55	1·0
Totals . .		780	4,752	100·0

	Miles.	Chains.
Length of curves	59	32
„ straight	35	47
Total distance, Nawalapitiya to Badulla	94	79
Percentage of curves	62·5	
„ straight	37·5	
		100

Number of Degrees of Curvature.	°	Circles.
To right	18,198 =	50½
„ left	18,630 =	52
Totals . . .	36,828 =	102½

TABLE VII.—PARTICULARS of the GRADIENTS.

Gradient. Exceeding.	Gradient. Not exceeding.	Number.	Total Length. Miles.	Total Length. Chains.	Percentage of Total Length.
Maximum	1 in 44	22	58	12·43	61·2
..	1 „ 49	1	..	46·0	0·6
1 in 50	1 „ 60	13	12	78·44	13·6
1 „ 60	1 „ 80	14	10	33·48	11·0
1 „ 80	1 „ 100	5	..	67·0	0·9
1 „ 100	1 „ 130	8	2	32·30	2·6
1 „ 130	1 „ 200	11	2	17·44	2·4
1 „ 200	1 „ 500	3	1	43·76	1·6
1 „ 500	1 „ 700	3	..	64·10	0·8
	Level	25	5	3·87	5·3
Totals		105	94	78·2	100·0

TABLE VIII.—CHIEF AVERAGE GRADIENTS and their HEIGHT ABOVE the SEA.

From.	To.	Distance.		Rise in Feet.	Fall in Feet.	Inclination.	Height in Feet above Sea.
		Miles.	Chains.				
Nawalapitiya	..	..	..	..	..	..	1,913
Nawalapitiya	Poolbank tunnel .	21	52	2,318	..	1 in 49	4,231
Poolbank tunnel . .	Talawakela	7	21	..	300	1 „ 328	3,931
Talawakela .	Summit .	23	73	2,286	..	1 „ 55	6,217
Summit . .	Haputale .	13	54	..	1,524	1 „ 47	4,693
Haputale .	Roehampton	1	78	115	..	1 „ 90	4,808
Roehampton.	Oodowerre	20	17	..	2,247	1 „ 47	2,561
Oodowerre .	Badulla .	6	24	..	388	1 „ 86	2,173
Totals . . .		94	79	4,719	4,459		

SUMMARISED in ONE GRADIENT on EACH SIDE of the SUMMIT.

From.	To.	Distance.		Rise in Feet.	Fall in Feet.	Inclination.	Height in Feet above Sea.
		Miles.	Chains.				
Nawalapitiya	Summit .	52	66	4,304	..	1 in 65	6,217
Summit . .	Badulla .	42	13	..	4,044	1 „ 55	2,173

TABLE IX.—ESTIMATED COST of the RAILWAY from NAWALAPITIYA to BADULLA.

Description of Work.	—	Estimated Quantities.	Estimated Cost in Rupees.	Remarks.
				Rupees.
Excavation .	Cubic yards	6,702,997	7,195,896	Per cubic yard 1·07
Tunnels . .	Lineal „	4,615	2,219,743	„ lineal „ 481
Retaining walls	Cubic „	164,357	1,101,574	„ cubic „ 6·70
Masonry and bridges . .	„ „	161,520	3,561,557	„ „ „ 22
Permanent way	Miles . .	95	4,564,877	„ mile 48,051
Fencing . .	„ . .	86½	245,113	„ „ 2,807
Cart road . .	„ . .	50½	277,153	„ „ 5,381
Miscellaneous	„ . .	95	72,608	„ „ 764
Stations . .	Number .	17	832,399	Average 48,965
Telegraph .	Miles . .	95	53,106	„ per mile 559
Way and works Total			20,124,026	
Land and compensation			479,861	
Supervision			934,507	
Rolling stock			2,221,692	
Grand total (Rupee taken at 1s. 9d.)			23,760,086	or £2,079,088 = £21,871 per mile.

[MR. JOHN CARRUTHERS.

Discussion.

Carruthers. Mr. JOHN CARRUTHERS said with respect to the relativ tages or disadvantages of taking a short and very steep, a a longer and somewhat flat gradient, the former plan l adopted in New Zealand, and the latter in Ceylon. A responsible for recommending the Government of New Z adopt the former method, it might be desirable that h give some more detailed description of the line than that in Mr. Maxwell's Paper. Of course the question was could not be settled on any general principles. Every rest on its own merits. Mr. Mosse had given satisfactor for adopting the longer line in Ceylon, and he thought give equally satisfactory reasons for adopting the shorte New Zealand.

The system of railways tributary to the Fell inclin Rimutaka range began at Wellington, passed over the through Featherston, and went to Napier, an importa A branch line passing the Tararua range by the Manawa a cleft in the mountains through which the Manaw passed, extended to New Plymouth, also an important t through a district which might, for its fertility and b called the garden of New Zealand. When the system pleted 400 miles of railway would be tributary to the Fel and all the traffic would pass over it in order to reach W the only sea-port worthy of the name throughout t district.

If the object of the Government had been merely t Napier and New Plymouth with Wellington, the line w passed by the west of the Tararua range, the summit be lower and easier than that over the Rimutakas; a branch the Manawatu gorge would then have accommodated Na had this been carried out the Wairarapa Valley (the mo district of the southern part of the north island) would h left without railway communication, and this could not especially as the railways were constructed by the Gov and the district was fully and influentially represented liament. The length at present tributary to the line 44 miles, but he hoped by the next mail to hear tha been opened to Masterton, a distance of 70 miles. A di 65 miles south of Napier had also been completed, leavi of 75 miles still to be filled up. To the west of the Ta

length of 120 miles had been completed, leaving another gap of 75 miles. The work was now in hand, and on its completion the total length would be 400 miles, all the traffic of which would pass over the incline. Mr. Carruthers

It was stated in Mr. Maxwell's Paper that the time of running from the summit to the foot of the incline, a distance of $3\frac{1}{8}$ miles, was from thirty to thirty-five minutes—say 3 miles in half an hour. The average speed on the New Zealand railways was 17 miles an hour, or $8\frac{1}{2}$ miles in the half hour, so that the system of railways tributary to the incline was less efficient than it would be without an incline to the extent of an addition of $5\frac{1}{2}$ miles to the whole length, a matter of no great importance. In other words, if there were no incline, and the line were level, the relative efficiency would be as 400 to $394\frac{1}{2}$ miles. The cost of working the incline could not be easily ascertained. The Fell engine was simply a bank engine used to push up a train at a pinch, as was often done elsewhere, and it was almost impossible to ascertain the exact cost of a bank engine. The line had been opened for a year without any hitch or trouble whatever, and there had been no expense beyond the ordinary repair of machinery. Of course the Fell engine was more complicated than an ordinary locomotive, but there had been no more difficulty in managing it than there was in managing thousands of machines in daily use in every manufacturing town. It had been stated by Mr. Maxwell that the cost of the locomotive service on the line from Wellington to Featherston increased 4*d.* per train-mile during the year after the incline had been opened. It would be wrong, however, to attribute that extra 4*d.* to the incline. Unfortunately, for two or three years before, the rolling stock had been allowed to fall out of repair, an error which was remedied on a change of management which was made two or three months after the incline was open. The extra 4*d.* was for putting the engines in repair on other parts of the line, not on the incline itself. The Paper was deficient with regard to statistics as to the cost of work. If there had been any trouble or accident in working, a great deal of statistical information might perhaps have been given, but as there had been no trouble of any kind, he could say nothing on the subject. He could not give the extra cost of working due to the incline, but in the course of a year or two the required information might be obtained. At present the incline was mechanically a perfect success. He might ask the members of the Institution to compare the incline with what might have been obtained by a gradient of 1 in 40, as indicated on the map. In setting out the latter the resident

Rathers. engineer had been instructed to run the gradient up the valleys until he could cross with an embankment of 100 feet at the centre line; and as the hillside often sloped 1½ to 1, an embankment of such a depth was a serious matter. He did not say that the line shown on the map really represented 100 feet at every gulley, because where there was a chance of getting a moderate curve the engineer went a good deal further up; but the general instructions were that 100 feet was to be the limit, and many of the valleys showed embankments of that depth. At the same time, in running round the points of the spurs, there were nineteen short tunnels in 8½ miles. The bricks, sand, lime and cement had to be carried on horses' backs, there being no possibility of making roads in such a wild country; so that tunnels were very undesirable, especially as they all required lining. The line for the most part consisted of 3-chain curves, reversing on the same point, and was longer than that finally adopted by 5½ miles. On the whole no one could hesitate in saying that the 1 in 15 gradient was far superior to the 1 in 40. It might, however, be a matter of opinion whether the Fell engine was the best means of working it. Without any centre rail a locomotive would take a load up that gradient; but in order to carry 50 or 60 tons, which the present Fell engine did, an engine depending solely on its own weight for adhesion would certainly have to weigh at least 60 or 70 tons; and an engine of that size and weight to go round 5-chain curves, forming, as some of them did, nearly a semicircle, would have to be a special machine, not less complicated than the Fell engine. He did not consider the Fell engine more complicated than the Fairlie engine, or the engine which Mr. Longridge had proposed for going up steep inclines, and in his opinion there could not have been a simpler system, even without the centre rail.

In laying out a very steep gradient he would certainly recommend that the tunnels should be made much flatter than the open parts of the line; this had not been done on the Rimutaka, and the great volume of steam belched out by the four cylinders working together, and almost without expansion, was so oppressive to the engine-men that it had been found necessary to put air-tight doors to the cabs. The tunnels being very short that method had proved sufficient; but in a long tunnel the heat and closeness would be unbearable; it would therefore be desirable and almost necessary to flatten the gradients, so that less steam might be used in the tunnels.

Mr. Maxwell had mentioned the occurrence of some break-

ages when the engines were first started. There were four horizontal wheels gripping the rails, each fastened on the lower end of a vertical axle, on the upper end of which were cog-wheels to keep the movements of the two pistons in unison. A spring of ordinary locomotive pattern was placed longitudinally on each side of the engine, with its ends pressing on the vertical axles, and the buckles of the springs, being drawn together by tooth gearing, pressed the wheels against the rail. It was expected that the pressure of the springs alone would be sufficient to keep the cog-wheels in gear, but to prevent accident a stud $\frac{7}{8}$ inch in diameter was placed on each side to keep the cogs from opening and fouling. The cogs, however, did open: the stud was too light to bear the pressure; it bent and allowed the cog-wheels to separate and to foul, and the teeth broke. As soon as the cause was discovered, a larger stud was substituted, and there had been no further accident. In designing a similar engine it might be as well to keep the spring a little higher on the axle, so that it would bring more pressure on the cog-wheels and keep them together. The engines had been made by the Avonside company, and were in every respect most creditable. Before deciding to recommend the Government to adopt the present plan, he had a strong preference for a rope and stationary engine, and had spent much time and labour in seeking a place where a moderately straight line with steep gradients could be located. He did not succeed in finding one, and abandoned the scheme; still he was so much in favour of it that he recommended its adoption in the event of Messrs. Hemans and Bruce, the consulting engineers, thinking that it would work as satisfactorily as the Fell engine. Mr. Bruce, however, endorsed his own opinion that on so crooked a line it would not be satisfactory, and the Fell engine was therefore adopted. The rack engine might also have been used; it had been largely adopted in Europe, but it had not been tested for heavy loads, and he did not think that so distant a colony as New Zealand was the right place for trying experiments; he thought moreover, from *à priori* reasoning, that the centre rail was superior to the rack engine, while it was known from the experience gained on the Mont Cenis line that the former was a sound and workable system.

Mr. Carruthers.

The method of exploring the country was different from that described by Mr. Mosse as having been adopted in Ceylon. The resident engineer, or the chief of the party, started ahead, and laid out a line with the help of an instrument which was jocularly termed a "clinometer," being a mason's 1-foot rule with

Struthers. a level in it, to which was attached a lath somewhat longer than the rule; the two were fastened together at the inclination of the gradient, and set on the ball-and-socket joint of an ordinary prismatic compass-stand. When the foot-rule was level, the lath was pointing at the inclination of the gradient; a man then went on ahead with a boning-rod, and was set in line at the right level. The "clinometer" was then brought forward, and the man went on again. Of course, in going round spurs and heads of valleys, a level line was carried round, and started on the other side at the inclination. The system required considerable judgment on the part of the engineer, but no one who had not seen it tried would believe how accurately lines could be levelled in that manner, and a good base line obtained from which the resident engineer could wander about on either side and point out where the line was to be shifted. Another officer followed with a chain and prismatic compass, and made a traverse of the rough line first laid out. Curves were afterwards laid down on the plan which would fit in between the gradient points, and by measuring off with a tape from the rough traverse could be marked approximately on the ground and properly levelled. At the same time cross-sections were made with another "clinometer," consisting of a shallow box with a glass face, at the bottom of which a semicircle was marked, a heavy pendulum being attached to show the inclination. From the information thus obtained the engineer could set out on the plan the final line, which could also be approximately marked on the ground, and then ten times as many axe-men could be employed to cut out the line, and the work could go on very much faster than by any other method he had seen adopted.

It appeared from intelligence received by the last mail that an accident had occurred, which, however, had nothing to do with the inclination. It was of a very extraordinary character. A train started up the incline with two passenger-carriages in front, then an ordinary brake-van, then an engine, then two loaded goods-vans and an incline brake. A gust of wind came and blew the passenger-carriages and the passenger brake-van completely off the line. As far as he understood, the carriages were not overturned, and did not touch the road until they were nearly at right angles to the train. The incline brake-van was thereupon detached and sent back for assistance, leaving the loaded goods-vans attached to the engine. In about five minutes another gust of wind blew the loaded goods-vans off the line. The New Zealand carriages were 7 feet 6 inches high in the side, and 6 feet from the rail to the centre of the side, while an ordinary English carriage was 8 feet

de, and 6 feet 9 inches from rail to centre. The relative Mr. Carruthers.
s against overturning by wind would therefore be, allow-
lifference of gauge, as 100 to 112 for equal weight per
ot. The weight, as given in Colburn's "Locomotive
ing and the Mechanism of Railways,"[1] of the North
Railway carriages was 7 tons 15 cwt. for a carriage 27 feet
l New Zealand carriages of the same length weighed
The relative stabilities would therefore be about as 100
wind pressure of 27 lbs. per square foot would overturn
'ealand, and of 33 lbs. an English, carriage. In this
not only the carriages, but also the goods-vans had been
ed; the latter were 15 feet long, 6½ feet in the side, and
om the rail to the centre of the side, and if fully loaded
ich information was not given) would weigh 10½ to 11
en if they only weighed 8 tons, it would require a wind
of 66 lbs. per square foot to overturn them, or twice that
to blow over an English carriage. The blowing away,
, even of an English carriage was by no means an
y danger; and the train lost at the Tay Bridge might
ve been overturned by the wind.

. B. Bruce said he had been responsible, together with Mr. Bruce.
uthers, for having advised the New Zealand Govern-
adopt the Fell engine to work a steep incline with
rail; because, although Mr. Carruthers, as representing
ernment in the colony, sent home the order for the
to be forwarded, it was, as he himself had explained,
reservation that the consulting engineers in England
be satisfied that that was the best method to be em-
eaving them to recommend anything else which might
be more suitable. He agreed with Mr. Carruthers in
that the best mode of working the incline was the intro-
f a central rail and the use of the Fell engine with hori-
heels, giving the necessary extra tractive power. Mr.
rs had shown clearly that he was right in adopting an
f 1 in 15, instead of 1 in 40, which would have involved
avier works and a much longer and more circuitous
her modes might have been adopted, such as that of a
ine with a rope, which, under suitable circumstances,
thought, the best way of treating such an incline. In
nt instance, however, the curves being sharp and pretty
, it did not seem to him to be wise to propose the

[1] *Vide*, p. 305.

Mr. Bruce. adoption of that method. The rack and pinion system had also been suggested—a method that had been successfully adopted in Switzerland, as had been shown in a Paper laid before the Institution a few years ago by Dr. Pole. That, however, was a gradient of 1 in 4. In New Zealand the gradient was 1 in 15; and when there was a gradient up which a locomotive could travel by itself, and could take something with it, he did not think it was desirable to adopt the method of working the cog-wheel into a rack. There was one objection to that mode of construction, namely, that the rack required to be very firmly and securely fixed. Dr. Pole had stated in his Paper that it was laid absolutely on the solid, and that at every 100 yards masonry was built up to secure it firmly.[1] In the case of a railway which was alternately on embankment and in cutting, as in the present case, it was impossible to get an absolutely solid bed for a rack. Under all the circumstances, he thought the best mode was that which had been adopted, and which appeared to have answered admirably. It had been stated that there was some difficulty in the first instance in regard to the cog-wheels, which were part of the locomotive itself, and drove the friction wheels which gripped the central rail. When the engine was tried at the Avonside works one of the cogs broke, and he thought the reason was that the wheels were made of cast steel, and that the teeth were cast as an ordinary casting. He believed that the difficulty might be overcome by making the wheels of hammered crucible steel, and cutting the teeth out of the solid. Accordingly, that was done in all the duplicate wheels sent out, and he thought that that had had something to do with the curing of the evil, which it was supposed had been effected by strengthening one of the parts. There was one advantage connected with the engines that perhaps would not apply to the rack, namely, that they would work of themselves on the ordinary road; and that, if necessary, they would take a train on to the station, because they could work independently of the central rail; indeed, it had been stated in the Paper that they had not only taken themselves up the incline, but also something of a load, without the use of a central rail. The wheels, which were not coupled upon the engines, were fitted up with Widmark's radial axle-boxes, which had acted remarkably well in assisting to go round the sharp curves. The Mangarangiora viaduct was a very well constructed one, and was an admirable mode of getting over a deep gulley—a

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvi., p. 106.

much better plan than building wide spans of timber-work with fancy trusses about them, where vertical frames could be placed in that way; it was an admirable mode of construction for a new country, and, indeed, for an old country. Nevertheless, he thought there was more timber in it than was necessary, and that the struts outside, which did nothing more than steady the three centre ones, might have been utilized to carry the load, and that some of the others might have been dispensed with. Thirty years ago there had been a temporary bridge over the Tweed, a great deal higher than that, with spans of 20 feet instead of 30 feet. Trains were carried over it for two years, and the Queen herself had gone across it. There was only one centre upright, with two outside timbers raking at about 1½ inch to a foot. In the viaducts in the Newcastle and Darlington railway, of which he had made the drawings forty years ago, under the direction of Mr. Harrison, Past President, there were only five timbers to carry two lines of rails. The spans were 20 feet. In the days to which he referred, no instance had occurred of the wind upsetting a railway train. In the Paper by Mr. Mosse it was stated, at page 66, with reference to bridges whose foundations were carried to a considerable depth, "This entailed great delay and expense, but in view of the numerous failures from the underscouring of bridges in India, the Author did not feel justified in subjecting the Government to the risk which a less secure foundation would have involved." That remark would almost lead one to imagine that the Author thought, in reference to bridges in India, that there had been an exceptional number of failures. He did not think that had been the case. India was a country with enormous lengths of railway, and although there had been some failures, they were comparatively few. Mr. Bruce.

Mr. F. J. BRAMWELL desired to say a few words in reference to what had fallen from Mr. Bruce as to the endurance of spur wheels in the central gear of the engine in question, or, indeed, of any spur wheels. There was a mode by which the risk of fracture might be greatly mitigated, and to which he knew of no objection except its unsightliness. Very commonly when fracture occurred it began at one end of the tooth, and did so for two reasons. One reason was that in wheels moulded from patterns in the ordinary way, and not moulded by a wheel-moulding machine, the necessary "draft" in the pattern caused one end of the tooth to be wider than the other; and if care were not taken, in putting the wheels to work, to put the large end of the one tooth to work with the small end of the other the great pressure would be thrown all Mr. Bramwell.

Mr. Bramwell. upon one end. The other reason was this: If it were desired to test the power of the tooth to resist fractures produced by pressure, then if that pressure were applied in the middle, the pressure was withstood by the metal on each side of it. The part pressed could not be broken away without breaking the metal on both sides; but if force were applied to the end, the tooth was then only upheld by the metal on one side, and in that way the end of the tooth was the most vulnerable part. All that was needed to preserve the ends of the teeth from being weaker than other parts was that the tooth, instead of being made vertical at the ends, should be made on an incline, so that when the two teeth were together the inclines overlapped each other. The pressure was then no longer applied to the extreme end of the tooth, but was applied inboard; and there was thus beyond the line of pressure a sufficient amount of metal to support the tooth. That was exactly what a carpenter did with a screw-driver that he wished to keep from breaking—he ground off the ends and made them into bevels. He had applied the plan he had described to wheels which had previously given a great deal of trouble; and after they had been altered in the manner described, they had given no trouble at all. The plan was simple enough, but was not generally practised. He did not know that anyone had adopted it but himself, but he could testify that beneficial results had followed its use.

Dr. Pole. Dr. W. POLE said that as Mr. Bruce had mentioned his name in connection with the Rigi railway, he might state that he perfectly agreed that the rack principle there used ought to be considered as an exceptional thing, only to be applied in extreme cases, where no other system was possible. The Rigi mountain was a case of this kind, where the alternative was between a gradient of 1 in 4 or no railway at all. No doubt, as Mr. Bruce had stated, the absolute stability of the rack was of vital importance.

It was, however, worthy of mention that the ingenious designer of the Rigi plan had, at a later period, been extending its applicability to cases of much more frequent occurrence, namely, where very steep gradients alternated with portions of level, or moderate inclines. The Rigi locomotive had a vertical boiler, and was suitable only for rack working; but he had lately designed engines of the usual form, with horizontal boilers, and which were so arranged that they would either run on their own wheels, by the ordinary plan of adhesion, or would, when required, turn a cog-wheel engaging on a rack laid between the rails. Dr. Pole had, a year or two ago, inspected a line of the kind now at work near

Berne. It united the great and ancient sandstone quarries of Ostermundigen with one of the stations of the main line of the district. The quarries were situated on a hill at some height above the railway, a mile or two distant, and to have gained railway access to them by a line on the ordinary system would have required a long detour and expensive works. Mr. Riggenbach laid out a cheap direct line, which first passed for some distance along the flat valley, and then mounted at once to the quarries by an incline of 1 in 10. The locomotive worked on the flat part in the ordinary way, and on arriving at the incline the toothed wheel was thrown into action, gearing into a rack laid for the purpose. Dr. Pole had travelled upon it, up and down, and it appeared to work very well, and to perform very useful duty at probably a more moderate cost than could have been obtained by any other means. In descending the steep incline, with heavy loads of stone behind the locomotive, the peculiar brake system, copied from the Rigi, came into use. Some care was necessary in bringing the tooth gear into action; but this was facilitated by ingenious mechanical arrangements designed for the purpose. The construction also of the locomotive for mixed purposes had been ingeniously designed; and Dr. Pole believed that descriptions of such engines had been published in the English engineering periodicals.[1] Dr. Pole.

The railway just described was only one of many which had been carried out by the same engineer in different parts of Switzerland and other hilly countries in central Europe, where the peculiar nature of the ground rendered lines of this compound kind, for light traffic, very applicable and advantageous. In such lines the same engine would work by adhesion on any gradient up to 1 in 40; and, with the aid of the rack, on any steeper gradient up to 1 in 4.

As the present discussion had specially in view the alternation of flat and steep gradients, Dr. Pole might mention a proposed plan of working these, which, though it had not been yet carried into practice, had been favourably viewed on the Continent, and had at least the merit of novelty and ingenuity. It was due to Mr. Louis Gonin, Engineer-in-Chief of the Ponts et Chaussées of the canton of Vaud, Switzerland, and was described in a pamphlet to be found in the library of the Institution.[2] It was well known

[1] *Vide* "Engineering," vol. xxiii., p. 413.

[2] Notice sur l'ascenseur à air comprimé, pour Chemins de fer à fortes rampes, et à profil varié. Par Louis Gonin. Lausanne, 1880.

Dr. Pole. to all who had studied the structure of the great Swiss vall that they seldom followed a uniform slope, but usually consis of alternations of steep gorges with comparatively level plai To trace, therefore, a line of uniform gradient up these vall was generally a very difficult and expensive matter, involv long detours and costly works on the hillsides. Mr. Gonin p posed to take the bolder step of making the levels of the l follow more nearly the natural profile of the valley, taking al nately comparative levels and very steep inclines; the novelty the plan being, that he proposed to use the same locomot throughout; and to help it up the steep parts by a fixed pneum power, applied in a somewhat similar manner to the old w known atmospheric tube, but using compressed air instead exhaustion. Mr. Gonin believed that this change would ren the whole arrangement much more manageable and effecti It would give a much more powerful force, with a moderate sized tube, as a pressure of several atmospheres might be us and the valve, being internal instead of external, would be l liable to derangement and more certain in its action. When train arrived at the foot of the incline, a bar, attached to the pis in the tube and protruding through the valve opening, would allowed to abut against some part of the engine, and by the f of the compressed air, thus aiding the normal working of engine, the ascent of the incline would be effected, after wl the pneumatic bar would be disengaged and the train would on its way without derangement or loss of time. It was also important feature of this proposal, that in descending the s inclines the tube apparatus would again be attached, when gravity of the train, urging the piston forward, would comp the air during the whole descent, which would not only act powerful brake, but, since the compressed air could be store reservoirs at the foot of the incline, the power developed gravity in descending would be rendered available to aid ascent at a future time.

. Longridge. Mr. J. A. LONGRIDGE said that before entering on what was p liarly the subject of the Paper, the relative advantages of con trating ascents into a steep gradient rather than seekin diminish them by expensive works and length of line, he des to mention a few circumstances connected with the Fell sys He had on one or two occasions mentioned certain facts conne with it, but he had never put before the members any authe statement as to the working expenses of the line. He had pers charge of the line during nearly the whole period of its work

from the end of June 1868 to the 15th of October 1871. There had been run during that time 345,000 train-miles; and he had before him the cost of the working as taken from the books of the company. On the average of the six years the cost of the permanent way was 1*s.* 7*d.* per train-mile, 4*d.* of which was perhaps due to the snow. The locomotive department cost 4*s.* per train-mile. The average working expenses for the whole period, from the 15th of June 1868 to the 15th of October 1871, had been as follows:— Mr. Longridg

Mont Cenis Railway.—Working Expenses from the 15th of November, 1868, to the 15th of October, 1871. Total train-miles, 345,520.

Average expenses per train-mile.

	s.	*d.*
Permanent way	1	7
Locomotive department	4	0
Carriage and wagon department	0	7¾
Control and traffic department	3	5¾
Total	9	8½
Receipts	11	9½

Locomotive expenses per train-mile.

	s.	*d.*	*s.*	*d.*
Working—				
Fuel and wood for lighting	1	3·14		
Oil and grease	0	2·50		
Drivers and firemen	0	5·10	2	5
Cleaning	0	1·71		
Water	0	1·26		
General charges	0	3·24		
Repairs—				
Materials	0	5·62	1	7
Wages and general charges	1	1·20		
Total			4	0

Average consumption per mile, including pilotage and shunting, for the whole period.

	Lbs.
Fuel—Coke and briquette	81½
Wood for lighting	6½
Oil	0·405
Grease	0·005

Average speed between stations.

	Ascending.	Descending.
	Miles per Hour	
S. Michael and Lansleburg	13·2	13·2
Lansleburg and Frontier	7·9	10·6
Frontier and Sara	8·6	10·6

Longridge. The quantity of fuel used per train-mile was 81½ lbs. The rulii gradient between Lanslebourg and Susa was 1 in 12½, with curv of 40 mètres (132 feet) radius. The speed was 8 miles an hour hill and 10½ down hill. No accident occurred from the beginni to the end of the working, and the line carried an enormo number of passengers. The conclusion he arrived at was that t Fell system was a mechanical success, but that it was expensive, would be seen from the fact that the cost of locomotive pow alone was 4*s.* per train-mile. He could not agree with l Carruthers that the Fell engine was not a complicated machi It was about as complicated as a watch. There was scarcely a l of room in it that was not filled up by machinery. In the lat Mont Cenis engines, upon which the New Zealand engines s peared to be modelled, there were four cylinders, two sets eccentrics, piston-rods, cog-wheels, &c. In the other engines, which there were fourteen, there was only one set of cylinde but there was a complicated arrangement which transferred t motion to the horizontal wheels from the cross heads. He did n say that a complicated machine might not work well: a wa was complicated and it worked well for years, but a watch w very different from a locomotive. He was constantly on the li for two years, and could state that it was impossible to wo the engines without a very large outlay. It had been stated th the New Zealand engines had plenty of steam to supply both t cylinders. That, however, was contrary to his experience. T Mont Cenis engines had boilers quite as large as the one describ and it was found that they could not supply steam for b the cylinders. Indeed he had found that in ordinary circu stances he could work the traffic as well with the central rail with the ordinary rails, or with the ordinary rails as with central, but that he could not get steam to work with both. he had been content to bring the speed down to 2 or 3 miles hour he could have followed up the pistons with steam, and co have taken a heavier load, but with a speed of 8 miles an h that was impossible. It was not possible to take more load the hill with two sets of engines than with one. There was thing that had given them a great deal of trouble, and he did know how it had been overcome in New Zealand. The t cylinders were worked with practically the same blast-pipe, any rate into the same chimney, and it was impossible to k the two engines beating together. The driving wheels were different sizes; even if they were the same they could not keep beating together. Every now and then the two cylind

were discharging at the same time; consequently there was a terrific pressure, and huge pieces of coke were torn out of the fire-box and jammed up the tubes. It was stated that the New Zealand engines would only take 14 tons up an incline of 1 in 15 without the central rail; one of the Mont Cenis engines, however, 21 tons in weight, constantly took a load of 24 tons up an incline of 1 in 12½. For months he worked the line without a central rail, simply with the ordinary wheels. The central rail gear was broken down; for months the line was worked without it, and he regularly took up trains of 21 tons, and sometimes of 24 tons. He therefore could not understand how the New Zealand engines, which were 36 tons weight, could only take 14 tons up an incline of 1 in 15. Something perhaps might be due to a want of proper sanding apparatus, which in the case of steep gradients was one of the most important things to which attention could be given. With a proper sanding apparatus one could work with a coefficient of ⅛th, and sometimes of ⅜ths. The sand was specially important with regard to the central rail. There was great difficulty in sanding it because the surfaces were vertical. Accordingly some cakes made of resin and sand mixed, had been put in boxes, which were applied to each side of the rail with a certain amount of pressure, so that the resin and sand could be rubbed off. That method was found to act exceedingly well. But, as he had said, without any central rail gear the engine could always take up its own weight. The subject of concentrating gradients was one in which he had taken great interest for many years. He had intended to bring the matter before the Institution, but it was impossible to do so without also entering upon the question of the locomotive, and as he had himself patented a locomotive for the purpose, he thought that if he had brought the subject forward it would look like using the Institution for his own purposes. The patent, however, had lapsed, and as any one was now free to use it, he had no longer any hesitation in alluding to the engine and describing what he considered to be its peculiar merits. He had been led to propose the engine by his experience on the Mont Cenis line. He felt certain that Mr. Carruthers had exercised a wise discretion in adopting a steep gradient instead of a gradient of 1 in 40. He had carefully investigated two or three cases bearing on the subject. The first was a portion of a line which he constructed in the Mauritius, where there was no gradient steeper than 1 in 80, and he had taken the same section and laid it out with gradients of 1 in 20; at the same prices, and using the engine of the description which he proposed, he in that way reduced the earth-

Mr. Longridge

ongridge. work from 22,000 cubic yards per mile to 4,200, and also redu
the total cost of the line from £6,810 to £3,320 per mile.
engine which he proposed to use would draw the same load up
incline of 1 in 20 that the present engines drew up an inclin
1 in 80. Assuming the traffic to be the same the working expe
would show very little difference. In the second case he wante
see what an average line in an average agricultural county in E
land could be made for, and he accordingly took the country
tween Leeds and Derby, with which he was well acquainted.
took the section of the present line and laid down a gradien
1 in 20, keeping the same location without varying the line,
he found that he could make a line sufficient to work the tr
at £10 or £12 per mile per week, for £3,000 per mile, exclusiv
the land. He was sure that that could be done in any ordi
country. That showed how large a saving could be effected
steep gradients. That, however, was not the only saving.
only could a railway be made for so much less per mile,
there were a great many less miles to make, and that was re
the important point to which he wished to refer. He would
it down as a principle which he believed was almost univers
true, that to get over a summit by means of what was ca
"development," it was better to seek only such a develop
as would give a gradient of 1 in 15 to 1 in 20, he should pr
the former, than to seek a development of 1 in 30 or 1 in 40. S
years ago he had published a pamphlet,[1] in which he had g
into the details of the question, and he would now only br
explain the results at which he had arrived. Supposing a rail
to be made between one point and another in nearly a straight
say a distance of 80 miles, by adopting a section which woul
got over with a gradient of 1 in 30 or 1 in 40, without any
heavy works, but that between the 50th mile and the end t
was a range or summit of, say 6,000 feet, which could no
tunnelled. A development might be made which would gi
gradient of 1 in 30, or a much shorter one might be made by ta
another course and adopting a gradient of 1 in 15. He had
the accurate sections, but he took approximate sections, suffi
to give a general notion of the character of the works requ
and he found that with a gradient of 1 in 30 he would hav
develop in one case 75 miles, and in the other case 37½ m
The total length of line in the one case was 134 miles, and in

[1] *Vide* Railway Extension. By James A. Longridge, 1877. Inst. C.E. T
8vo., vol. 279.

other 92 miles. He had carefully calculated the cost of working a certain amount of traffic. Taking 60 tons of traffic transported daily from end to end, and forty passengers, he had worked it out £7 per mile per week. In the one case there were 135 miles to construct against 93, and the cost per mile was £5,896 against £4,268. The capital required in the one case was £795,000, and in the other £395,000. The engines proposed to work the two lines would be 28 tons and 40 tons respectively. The comparative length of line and working extensions were shown in the following Table:— Mr. Longri

COMPARATIVE COST of LINE and WORKING EXPENSES.

	Gradient.		Per Train-Mile.	
	1/30.	1/15.	1/30.	1/15.
Miles to be constructed	135	93	..	..
Cost per mile	£. 5,896	£. 4,268	..	..
Capital	794,780	394,363	..	..
Weight of engine	Tons. 24	Tons. 40	..	..
„ for adhesion	18	40	..	..
Minimum radius of curves allowable	Feet. 250	Feet. 90	..	..
Weight per wheel	Tons. 3	Tons. 2½	..	..
Weight of rails per yard	Lbs. 40	Lbs. 32	..	..
Goods mileage	Miles. 161,760	Miles. ..	..	..
Passenger „	98,406	..	..	..
Total „	260,164	178,303	..	..
Cost of working:—	£.	£.	s.	s.
Station department	2,435	2,435	2·247	3·278
Permanent way „	10,692	7,496	10·097	10·090
Locomotive „	20,555	16,609	18·960	22·745
Traffic and carriage department	3,118	3,118	2·872	4·190
General management	2,100	2,100	1·539	2·245
	38,880	31,958	35·715	42·158
5 per cent. interest on capital	..	..	36·660	21·072
			72·375	63·330
Receipts	56,085	56,085	51·75	75·50
Dividend on capital	Per cent. 2½	Per cent. 6¾	..	..

To conduct the traffic they had to work 260,000 train-miles over the line with gradients of 1 in 30, and 78,000 over that with gradients

agridge. of 1 in 15. Taking the capital into account at 5 per cent. int
the expenses amounted to 72·37*d.* over the gradient of 1 in
against 63·30*d.* over the gradient of 1 in 15. Taking also into ac
the smaller number of miles to be constructed, it appeared th
traffic would have paid 2½ per cent. in the one case, and 6½ i
other. The figures might perhaps be slightly modified, b
believed they were substantially correct, and if so he maint
as he had done for a long time, that in such a case, where i
necessary to develop, it was best to shorten the line as mu
possible to reduce the capital account, and spend a little
money in the locomotive department. The question then
was it possible to work such gradients as 1 in 15? His repl
that he had worked a gradient of 1 in 12½ without a centr
for months. The difficulty he then had was that he could n
an engine big enough to do more work. With curves of 40 r
(132 feet) radius he could not have a longer wheel-base than
and upon a wheel-base of 8 feet, the engine overhanging alm
the verge of danger, steam enough could not be obtained.
was, indeed, hardly steam enough with heavy loads to
up what could have been taken in favourable circumstanc
the rails been in a good condition. He maintained that if
two pairs of driving-wheels one and a quarter times the w
of the engine, could be taken up, if he made four times
number of driving wheels he could put on a much larger
and reduce the weight per wheel, and get what adhesi
required. It was upon that principle that his engine w
signed; he preferred to put the cylinders in a vertical po
The driving axle was coupled to two pairs of wheels i
middle bogie. The middle bogie, although it could not
laterally with regard to the line of the boiler, was free to
up and down. The boiler was not fastened; it moved u
down, and the axle moved with it. The distance betwee
axle and the cylinder was constant, consequently the
were perfectly true throughout, and in that way they ove
all difficulty of springs interfering with slide action. A f
advantage of the arrangement was, that, whatever the posit
the engine, the weight was always the same, and equally distri
over all wheels, and this was an enormous advantage. A
tires would wear uniformly, and thus one of the sources of fr
in coupled engines was got rid of. Having got elasticity
vertical plane, the next point was how to get it in a hori
plane. That was accomplished by coupling the bogies to
by means of cog-wheels. That plan had been adopted c

Semmering incline many years ago; but the cog-wheels were keyed firm to the axles, so that when the axles radiated the wheels were thrown slightly out of truth. If the way was not perfectly level the wheels inside would be higher than the others, and one threw a twist upon the cog-wheels. The result was that, being made of cast iron, they wore out rapidly. According to his arrangement the wheels worked as true at whatever angle, within ordinary practical limits, as if they were fixed in a cast-iron frame in a factory. All the sixteen wheels were coupled, and there was the same weight upon each. The engine, of which a model was exhibited, would be 72 tons in weight, 4½ tons on each wheel. It had 2,500 square feet of heating surface, 200 square feet of fire-box surface, 2,300 square feet of tube surface, and would evaporate 406 cubic feet of water an hour. It would take a load, independently of itself, of 130 tons up an incline of 1 in 15. It would run round curves of 90 feet radius. He believed that was an engine which would enable steep gradients to be worked with facility and success. Gradients of 1 in 30 were now frequently used, whereas in former days a gradient of 1 in 100 was considered sufficient. He did not think that there was the slightest difficulty in working a gradient of 1 in 15, and if so he felt sure that a system of developing ought to be followed such as he had described, making the line as short as possible. Mr. Longri

Mr. Henry Maudslay had been both in Ceylon and New Zealand, having been in the latter colony when Mr. Carruthers was in full charge. He might be permitted to say that the object of his cousin, Mr. Maxwell, was simply to write a [Paper that might lead to a discussion on the character of a railroad suitable for that extraordinary country. Those who had never seen the New Zealand bush would have no idea of its real character. A person entering it with an ordinary pair of trousers would come out without a shred. Parasitic creepers 70 or 80 feet in length grew in every direction, the country was volcanic, and the surface was very rough. Railroads were chiefly required in connection with the harbours on the coast, and they were also needed for the conveyance of materials to the interior for the continuation of those lines. He believed that the easiest and most rapid mode of construction in a country of that sort was that which had been adopted. Ceylon was a country of a different character, with a large population, and requiring a different form of railway. It was not a question as to which gauge was itself the best, but which was best suited for the necessities of the two islands, according to their population, cultivation, produce, Mr. Mauds

Maudslay. and the like. New Zealand had yet to be peopled and cultivat while Ceylon had been inhabited and cultivated for centuries, s hence the different forms of railway which the engineers l considered it desirable to adopt.

Sir John Coode. Sir JOHN COODE said there appeared to exist some amount incredulity as to the possibility of a train having been blown the line in New Zealand. He held in his hand the latest inte gence received from the colony on the subject, and might perh be permitted to read a few lines with reference to it. "An inqu on the bodies of the three persons killed in the railway accid reported last mail proves that the mishap was solely attributa to the force of the wind, and that no blame whatever could attached to the engine-driver or others employed." There t appeared to have been a thorough investigation into the subj and the result arrived at was that the accident was due to the fo of the wind and to that alone.

r. Grover. Mr. J. W. GROVER remarked on the statement in Mr. Maxwe Paper that a gradient of 1 in 40 would require a line of 8½ mi in length, while a gradient of 1 in 15 would require only a len of 2½ miles. It appeared that in one case there was an asc of 1,122 feet, and in the other case an ascent of 880 feet. presumed that on the line laid out with gradients of 1 in there would be some pieces with a less steep incline. The r comparison would be 8½ miles against $3\frac{3}{16}$ miles. The statem of Mr. Longridge that he had worked the Fell engine without use of any central rail up an incline of 1 in 12 reminded him the story of a corkscrew, which had the advantage that if it co not be used in the way the patentee proposed, it could be used as ordinary corkscrew. He would venture to suggest whether it not possible to do in New Zealand what had been done with s success in Mexico. There was a very steep incline between V Cruz and Mexico; for about 13 miles there was a continu gradient of 1 in 25, and it had been regularly worked by the o nary pressure of iron upon iron—the simple adhesion of wheels of the Fairlie 62-ton engines. These engines went ro curves of 350 feet radius, and would take a gross load of tons. That, of course, was sufficient for most mountain railw and certainly for the line which Mr. Longridge had mentio as earning £7 per mile per week. Taking the weight of engine as 1, the gross load was 2·4, making a total of 3·4, wh would give with the gradient in question a coefficient of 7 The Mauritius 37-ton engine on a gradient of 1 in 27 would g a coefficient of 1 in 10. The 48-ton Mauritius engine gav

coefficient of 1 in 10; the Fell engine 1 in 6·2, the Maddison 50-ton engine, taking a load equal to itself up 1 in 16½, represented a coefficient of 1 in 8·25. A gradient of 1 in 6 could be ascended by an engine by itself; and Mr. Longridge had gone so far as to say that it could go up a gradient of 1 in 4½ by the aid of a sand-box. That accorded with the experiment of Stephenson, who tipped one piece of iron resting on another till it began to slide, which was at an incline of 1 in 4½. That, however, could not quite be done with steel upon steel. On the Taff Vale railway there was a gradient of 1 in 18. The gradient was formerly worked by ropes, but now the ordinary locomotive took up a load greater than its own weight, namely 45 tons, the engine being 36 tons. Between Manchester and Oldham there was a gradient of 1 in 27, and there engines of 29 tons could drag up from 60 to 80 tons. The question really came to this, whether, if the engineer who had laid out the line in question had adopted a gradient of 1 in 25, he could not have worked it by the actual pressure of the steel tire upon the steel rail, without the assistance of his ingenious arrangement for gripping the rails. The experience in Mexico, he thought, went far to prove that such was possible. In a recent paper Mr. Maxwell stated, "Some of the double Fairlies are in use on the worst lines, and some single Fairlies, which were procured on the advice of the late engineer-in-chief, Mr. Carruthers, and which perhaps are the most efficient and useful engines on the steep gradients and the 5-chain curves which we have. The single Fairlie is carried on one six-wheeled bogie and one four-wheeled bogie." It appeared to him that for mountain railways the Fairlie engine provided what was most of all needed, a large boiler power, and the whole weight used for adhesion, together with a possibility of going round very sharp and very numerous curves. A railway, like an ordinary road, should follow the different gorges which always existed in a mountainous district. He might be permitted to mention that the first twenty-four carriages sent out to New Zealand had been designed by Messrs. Hemans and Bruce, on an arrangement invented by himself to enable them to traverse very sharp curves. There were many ways of going round sharp corners, but his arrangement had the advantage of giving a radiation to a four-wheeled stock. There were eight-wheeled and six-wheeled bogie carriages, but he believed his was the only one in which a practical arrangement had been adopted for a four-wheeled stock. He had received a report from the manager dated Napier, 3rd February, 1879, in which he stated with reference to

Mr. Grover.

Mr. Grover. the Grover carriages, "They have been in general use since October 1876, and have run about 64,000 miles. In my opinion they are the best carriages we have on this section. I find they wear the wheel flanges less, are more comfortable, and oscillate less than the other carriages which are of the four-wheeled and six-wheeled type (with bogies). They have required but little in the way of repairs . . . . they give, my carriage foreman tells me, less trouble than the other classes of carriage stock." He exhibited some photographs of the carriages, and also a model. These carriages were used for the Barbadoes railway, the interiors of which were unequalled for decoration. They were not designed by himself. Reference had been made to the mode of surveying mountain railways. He had himself laid out a very rough piece of mountain railway round the face of the Andes, below the city of Carracas. It was 3,000 feet above the level of the sea and only 8 miles from the coast, but a mountain 9,000 feet high intervened between the city and the sea, so that there was considerable difficulty in connecting the two places. The instrument which he exhibited proved of very great service in the survey. It was necessary first of all to get a track round the face of the mountain, and to find the levels, and then to work down with an aneroid barometer, so as to get the proximate position of the line. A man started cutting through the bush, with the instrument set at the required gradient; it turned on a pivot, and the men were able to locate the line round the different gorges. It would be seen from the size of the box that the instrument was very portable and suitable for a tropical climate.

Mr. Welby. Mr. Richard F. Welby observed that he had long resided in Brazil, and was in a position to state that on the Nova Friburgo railway the Fell system had been in use many years; but he had been informed by the manager of that line that it was under contemplation to abandon that system in favour of ordinary locomotive engines. The question under discussion seemed to be whether the locomotive in itself could be made a successful climbing machine. The steeper the gradient the heavier the locomotives would have to be, till, as the gradients increased, the best constructed climbing locomotives could only draw a load equal to their own weight, and thus became ponderous, clumsy expensive contrivances. The limit gradient at which a locomotive could be successfully employed was, he imagined, 1 in 15. No doubt locomotives could ascend much steeper gradients; he had once driven an ordinary locomotive, without any load, up the incline planes of the Serra do Mar of the São Paulo railway, which

had a gradient of 1 in 9·75, but that was no proof that they could be successfully employed for working traffic on such a gradient. Inclined planes were now becoming popular in Brazil, for besides the important inclined planes of the São Paulo railway, one small line for passenger traffic in Rio de Janeiro had been successfully worked three or four years, no accident having occurred upon it. It had gradients of about 1 in 8, and was worked with one of Fowler's clip pulleys. Another inclined plane was about to be established to connect Rio de Janeiro and a neighbouring suburb. It would have an average gradient of 1 in 7 on each side the summit, with a total length of about 800 mètres. A stationary engine was to be fixed upon the summit, and it was intended that the passengers should be wound up on one side and let down on the other simultaneously; ordinary brakes would be used, but as a precaution the clip blocks, as adopted on the São Paulo railway, or a modification, would be attached to the carriage. He hoped that locomotives would ultimately be superseded either by electricity or some other motive power. Mr. Welby.

Mr. F. A. SHEPPARD said he had visited both Ceylon and New Zealand. He had listened to the Papers with great pleasure, because knowing the countries well he could appreciate the difficulties experienced by the engineers in laying out the lines. Reference had been made to crossing the saddle of the Rimutakas, and the description was an accurate one; for he had himself sat upon a ridge with one leg upon one side and the other upon the other. With regard to the Valley of Pakuratahi, he might mention that his brother, Mr. Robert Sheppard, surveyed it in the year 1844. He thought that an improvement might be made in regard to the location of the curves in lines such as those in New Zealand. It had been stated that there were 3½ miles with 5-chain curves, and 7 miles with curves of 10 chains radius. He was of opinion that parabolic curves ought to be adopted for small lines of that description. When a locomotive was oscillating on a straight line, as soon as it entered the arc of a circle it would keep oscillating round it almost as in a straight line, but with a parabolic curve the oscillation with which it entered the line was diminished as it went up to the apex, and as soon as it passed the apex the diminution would continue. Thus the oscillation must be considerably reduced, and consequently the wear and tear of the carriages diminished. With regard to the different kinds of wood, he agreed with Mr. Maxwell that the totara was most suitable for all purposes, but that the matai was too hard. As to the question of gauges, railways of a larger gauge had pretty well filled up all Mr. Sheppard.

Sheppard. the old countries of the world, and narrow gauges appeared to be more suitable for younger countries. The circumstances of each country should be studied in order to see which gauge was most applicable to it. He thought that many mistakes had been made with reference to that subject. Nothing had been said as to the desirability of so constructing a narrow gauge that it could be enlarged when the population increased. In China he had laid out the first railway at Woosung, forming the embankments from side cuttings on one side only. He had wished to make it on a large gauge, but a 2 feet 6 inch line was laid, and ultimately it was taken up and thrown into the sea.

Mr. Scott-Russell. Mr. J. SCOTT-RUSSELL thought that the discussion had brought out important additional information as to the nature, use, and limits of gradients, namely, that on a gradient of 1 in 15, or 1 in 14 (with which he was most familiar), an engine with all its weight resting on driving wheels, could take itself up, and also an equal weight behind it. That was one of the most valuable facts that a practical engineer could have in his mind in making an engine for a steep gradient. He had himself proved that an engine could go up a gradient of 1 in 7 with the mere bite of the wheel. Doubling the figure, and making it 1 in 14, exactly double the weight could be carried, namely, the engine itself and its own weight behind. Doubling that again, and taking a gradient of, say, 1 in 30, an engine could take itself up the incline and three times its weight behind. Those were very important data, but he did not remember to have heard them brought forward before, even by his friend Mr. Woods, who, with himself, had probably made more experiments in gradients than all the rest of the world put together. Their experiments were all recorded in the Transactions of various institutions, but none of them had come up to the critical point at which they had now arrived. It was only when he was in Asia Minor, where some very sharp lines were made, that he was able to ascertain from critical experiments that up to 1 in 14 a common navvy's engine would pull not only its own weight but an equal weight behind it. He did not think that the English had made as good engines as other people for going up steep gradients. They were prejudiced in favour of bigger wheels, and also in favour of a shorter stroke. All the good engines that he knew abroad had at least a 24-inch length of stroke for steep gradients, and a 24-inch length of stroke upon wheels of extremely small diameter; their power, therefore, was enormous. Putting upon that a big fire-box they would get all that was wanted

ıe purpose. He did not think toothed wheels and racks good things for railway traction. They were not con- ıt, or lasting, or safe, and they were very costly. He wished : the simple question, Why, having a central rail and what alled a Fell engine, why not make in the first place air of engines instead of two? Again, he wished to ask, not, in a Fell engine, make the grip of the central rail from the same source and the same axle as the grip on rdinary rail? and why not make the central rail so as y to give that grip? He was not going to answer the on, but he would say that a Fell engine might be made the grip on the central rail with only the same set of engines, and wheels, as with the grip of the engine with ordinary s. If the members, after considering the subject for a month), did not succeed, he would show them how to do it. He een once asked to advise an important Government as to ıys to be made in a country as steep as New Zealand. He sed even a smaller instrument than that shown by Mr. Grover tting round curves and corners, and he employed a "dodge" he would briefly explain. The plan was to take one of the ments that had been described, together with a telescope would measure distances, and to send a man or men each a staff, the length of which was known and graduated extreme accuracy, and a plumb-line. The staff was placed stone or station, so that the whole of it could be seen, and the instrument not only could the angle be taken, but the distance could be measured. In that way a preliminary y could be made in a mountainous country in one-tenth of me required by any other mode. Nothing was so important ıt when an engineer went to survey a strange country he l go uncommitted as to gauge, or curve, or gradient. The ry itself, and its circumstances, should dictate the nature of ailway, and the engineer's own "crotchets" should have ıg to do with it. With regard to a very narrow gauge, he ıt think that it had many good qualities, and, like a previous er, he should like to see it flung into the sea. Having given attention to the subject, with some prejudices in favour of ırrow gauge, he had altogether dismissed it as an insanity folly. The going over a curve and its resistance had little thing to do with the gauge of a railway. He knew it was sy to say so. It might be proved mathematically that it not be so, but he simply stated that it was so. He had never friend to the broad gauge, but he did not think more trains

Mr. Scott-Russell.

Mr. Scott-Russell. had gone off it than had gone off the ordinary narrow gauge. Taking a properly formed rail with a proper amount of slack between the two, and those charming parabolic curves, to which reference had been made, taking all those things together, there was not a single element of safety or economy in the narrow gauge. Taking the breadth of the roadway as 11 feet, having a bit of steel 50 lbs. to the yard, and another bit of steel 50 lbs. to the yard, one person laying them at a distance of 3 feet, another at 4 feet 9 inches, and another at 5 feet 3 inches, there being a given weight and a given railway to carry it, what was gained by having the rails a little nearer together or a little farther apart? He hoped the members would look into the matter carefully before pretending, or allowing anybody to pretend, that there was some wonderful virtue in that little exceptional gauge. People might fancy that it would fill their pockets, but it would be thrown into the sea in the course of a year or two.

. Gregory. Mr. CHARLES HUTTON GREGORY, C.M.G., Past-President Inst. C.E., said he regretted that Mr. Mosse was not present; but if any further information upon details should be desired, Mr. Strong, the resident engineer of the Ceylon railways, who had been in the colony from the opening of the first section, would be happy to answer any inquiries. The attention of the members had been rather invited to a comparison of the merits of the different systems upon which the New Zealand and the Ceylon railways had been laid out, constructed, and worked; but he submitted that any such comparison would be entirely fallacious. In both cases those who had to direct the survey and construction of the line, and to settle the modes of subsequently working it, had to consider the special local circumstances with which they had to deal, the particular character of the country, and the nature of the traffic; these conditions widely differed in the two countries, and he should briefly endeavour to justify the system adopted in the Ceylon railways without making any criticisms upon the system adopted in New Zealand, which had been ably supported by previous speakers.

It would be remembered that the railways described in Mr. Mosse's Paper consisted of various sections. The original Ceylon railway, running from Colombo to Kandy—from the commercial to the old capital—was 75 miles in length. Subsequent extensions had been made, one along the coast to Kalutara, 26 miles in length; another to Nawalapitiya, 28 miles long; and another to Matale, 17½ miles long. The coast line was on flat ground, but it required very large bridges for rivers and flood openings. The line from Colombo to Kandy for the first 30 miles had no heavy

excepting some river bridges. For the next 20 miles the Mr. Gregory.
were very heavy. At a distance of 52 miles from Colombo
ne commencement of the Kadugannawa incline, with a
nt of 1 in 45, 12 miles in length, running on the side of
recipitous hills, almost overhanging the valley below; and
it arrived at Kandy the railway was in the middle of a
ain district. The northern part of the central province,
was the most fertile part of the colony in the production
ee, tea, and cinchona, was extremely difficult. Through
istrict the lines to Matale and Nawalapitiya had already
nade. They had, however, still greater difficulties to en-
r in the extension from Nawalapitiya to Nanu Oya, which
be carried out, and was under contract.

had first to justify the gauge adopted in these railways.
ceptionally narrow gauge had been favoured by many
ne time past, especially for colonial railways, and in many
its advantages had been greatly exaggerated and its dis-
tages greatly under-rated. He did not intend to revive
ing like a gauge discussion, but he ventured to say that it
have been very unwise if such a gauge had been adopted in
. There was a large traffic to carry, and that was one
it which helped to make a great difference between the
a and the New Zealand railways. They had not to create a
or open up a country, but to provide the necessaries of life
large agricultural population, and to bring back their pro-
to the port of shipment. He was responsible for the gauge
as fixed upon, and the gauge of 5 feet 6 inches was adopted.
as the members knew, was the Indian gauge, and it appeared
a that there were many reasons why it would be desirable
he same gauge should be adopted on the Ceylon railways.
eason for its adoption in India was the facility it afforded for
sing engine power, a reason very applicable to Ceylon. He
ht that there might be circumstances of emergency in which
eylon railway might be in want of engines or rolling stock
ally, which, if that gauge were adopted, might be supplied
ndia. Considering the large quantity of rolling stock made for
he felt that there would be no difficulty in obtaining what
be required in the English markets. Further, he had an idea
was then thought to be visionary, but which had lately
seriously revived by the Governor of Madras, that Ceylon
at some time be united with the mainland of India by a rail-
cross Adam's Bridge, leaving, of course, an opening for ships,
ossing the navigable opening (which was not of very great

Mr. Gregory. breadth) by a steam ferry. Last, but not least, he believed that in such a climate as that of Ceylon, where the rainfall was sometimes as much as 20 inches in twenty-four hours, it was necessary to make special provision for the stability of the railway, which would pass through a country where running off the rails might be attended with most disastrous results. The great quantity of water which would in many places run across the formation of the Ceylon railway would be likely seriously to disturb the level of the rails, and in such a case a wider base than usual would be a material safeguard. The propriety of the gauge was attacked at a very early period, and the attack came from a source that made the Home Government (which had guaranteed the railway, and had a veto upon all its proceedings) anxious to know whether the choice which the company had made at his instigation was right. When the difficulty arose, it was decided to take another opinion, and he suggested that if the President of the Institution of Civil Engineers were invited to report on the question, no one could take exception, or suppose that there was anything like favour or affection in the choice. Accordingly Mr. Locke, then President of the Institution, was appealed to on the subject, and another question was referred to him at the same time. The engineer who had disputed the propriety of the 5 feet 6 inches gauge had also asserted that lighter rails than 72 lbs. per yard would be sufficient, and while proposing the 4 feet 8½ inches gauge, recommended the use of a 50-lb. or 60-lb. rail. Mr. Locke investigated the questions, and although at that time there was a strong feeling in favour of the 4 feet 8½ inches gauge generally, he recommended the 5 feet 6 inches gauge and the 72-lb. rail for the Ceylon railway. At two subsequent periods an endeavour had been made, under the influence of plausible arguments, to introduce the 3 feet 6 inches gauge for the Ceylon railway extensions. That gauge was proposed for the extension to Nawalapitiya, but after some discussion, and, I believed, mainly under the advice of Mr. Strong, the idea was abandoned. Mr. Strong pointed out how very small the saving would be in such heavy works, and the enormous inconvenience that would arise from a break of the gauge—an inconvenience the continued existence of which in England was described, in the Report of the Royal Commission on Railways in 1867 (p. lxxxvi) as "a national evil." At a later period the gauge of 3 feet 6 inches was proposed for the extension from Nawalapitiya to Nanu Oya. The objections to the proposal were set forth in a very sound report by Mr. Mosse, but it was not abandoned un-

much valuable time had been lost in surveys, and estimates made which showed how small the saving would be compared with what was expected. Mr. Gregory.

The next question was that of gradients. It was stated in the Paper that the maximum gradient was 1 in 100, until arriving at the foot of the Kadugannawa incline, which had a continuous gradient of 1 in 45, and extended 12 miles and a few chains. There was a proposal at one time to introduce a gradient of 1 in 15, it being alleged that a considerable saving would result from the introduction of that gradient. He always doubted it, and the project involved stupendous works, which he thought would be most undesirable in a country where skilled labour was expensive, and where the works might be exposed to very severe weather. He accordingly recommended a further examination of the country, believing, from the original surveys made by Mr. Drane and subsequent surveys by Captain Moorsom, that a line with reasonable works could be found with a gradient of not worse than 1 in 45. He suggested to Mr. Molesworth that this should be the gradient upon which the incline should be laid out. Mr. Molesworth succeeded in finding a line which was a very good one, notwithstanding the severity of the country, and he did not believe that a better line could have been chosen. This result was very satisfactory, because it left the line in conditions as to gradients consistent with the use of ordinary locomotives. Upon the extensions to Matale and Nawalapitiya the maximum gradient was 1 in 50. They did not make any great struggle to avoid that gradient, because it was not in great lengths, and having already a gradient of 1 in 45, the engines which would overcome that incline would of course overcome a gradient of 1 in 50. Mr. Mosse had alluded to a question which he had raised, whether it would not have been desirable, in the extension from Nawalapitiya to Nanu Oya, a length of 42 miles, through a country which, he supposed, had few equals in point of severity and difficulty, to use a steeper gradient than that adopted. It was a subject of long and anxious correspondence between Mr. Mosse and himself. Mr. Mosse alleged very good reasons for such a gradient—that the line could be shortened and cheapened by its use, as no doubt it could, but believing as he did that it could not be shortened or cheapened very greatly, he thought it more desirable to have no worse gradient than 1 in 44, combined, as was necessarily the case, with curves of 5 chains radius; and that, considering the large amount of traffic which it was expected would be carried upon the line, and the greater risk that would attend the descent of long gradients

Mr. Gregory. if made steeper with 5-chain curves, it would be better and safe maintain as nearly as possible the gradient existing on other par the line. It would be remembered that they had to deal with a li traffic; and, notwithstanding the successes which were state have attended the ingenious inventions that had been made engines on steeper gradients, he should certainly desire, w the ground allowed it, to have no worse gradient than 1 in 4 1 in 45, as below that limit the cost and difficulties of worl increased very rapidly. There were no doubt special case which it might be best to accumulate the rise on a railwa a short and very severe gradient. Attention had been dire to a part of the Nanu Oya extension, where a deviation out in this view would, it was thought, materially shorten cheapen the line, and bring the severe gradient to a p where it could be worked by a large and constant fall water. But the deviation unfortunately would have taken line away from important sources of traffic, and it was sequently abandoned.

The curves on the mountain portions of the Ceylon railway v very sharp. He would gladly have adopted easier curves, bu was found that their use would have enormously increased cost of the railway. In reference to the Kadugannawa inclir curve of 10 chains radius seemed almost to fit the country, if they had used a sharper curve they could not have cheape the line very much. In the survey of the extension to Nanu 5-chain curves were in many places required by the characte the country. He had desired to have 10-chain curves, and surveys were directed to that object, but it was found that increased cost would be so great that they were obliged to ac 5 chains; and while an engineer would gladly avoid such cur experience had shown that they might be successfully worked engines of well-known and approved types.

In settling the character of structures for a railway in a country with small traffic, it might sometimes be the duty of engineer to recommend that, instead of making a railway comp and solid in every respect, it should be first made of a tempo character, and afterwards improved. It could not, however, alw be done. If timber structures instead of permanent structure masonry and iron had been used in Ceylon, what would have l the result? The only wood growing in the colony which w have been suitable for the purpose would not last for more t two years, and the members could easily imagine the inconvenie and danger of having to interfere with a very large traffic ev

two years by renewing bridges. The conditions of the Ceylon railways justified and required solid and substantial construction. The present structures had involved no great outlay. They were perfectly plain, as would be seen from the photographs and from the contract drawings which he had the pleasure of presenting to the Institution. They were solid and simple, and he thought that simplicity of structure was one of the essential elements in railways far away from home. Following well-known types that had been proved to be good was the safest course to adopt in such railways. That course had been followed in connection with the Ceylon railway, which had been worked hitherto without a single accident to a passenger, and with great financial success. Mr. Gregory.

In conclusion he hoped he had satisfied the members that the plans which had been adopted in laying out, constructing and working the Ceylon lines were fitted to the circumstances of the case.

Mr. P. O'MEARA said that from his point of view the adoption by Mr. Carruthers, with Mr. Bruce's sanction, of a gradient of 1 in 15, in preference to 1 in 40, was a step in the right direction. He referred to circumstances similar to those in New Zealand. He did not differ from Mr. Gregory, because the traffic in Ceylon and that in New Zealand were very dissimilar. Certainly he should not recommend a steeper gradient than 1 in 45 for such traffic as that in Ceylon; but if that gradient had been carried out in New Zealand he believed it would have proved a failure. The gradient of 1 in 15 had been even a greater success in New Zealand than appeared from Mr. Maxwell's Paper, in which one important item, economy in expenditure from the diminution of length, had been omitted. It had been stated that £5,000 a year would be saved in interest on the cost of construction, and that twenty-five minutes would be saved in every journey. With regard to the cost of working, it had been left doubtful by Mr. Maxwell whether there was any economy or not. Mr. O'Meara thought, though it might appear paradoxical, that there was in reality a saving in that item. The total working expenditure was said to be £22,919. If there had not been a loss in the locomotive expenses of $4\frac{3}{4}d.$ per train-mile, that expenditure would have amounted to about £20,300. Taking the proportion of 45 miles to $10\frac{1}{2}$ miles, there was a gain of £4,755, which was at the rate of $9d.$ per train-mile, leaving a clear saving of $4\frac{1}{4}d.$ in favour of the method adopted by the advice of Mr. Carruthers. There were several colonies in which the alter- Mr. O'Meara

r. O'Meara. native was between a gradient of 1 in 15, or a very light railw and none at all. He knew of a colony where no railways w made, in which the transport of imports and exports cost upwa of half a million a year. The colonists were obliged to pay and 2*s.* per ton-mile for their goods, and yet they could not ha a railway because the cost of construction would be so great th the interest would more than cover the total revenue of the colo In such cases, if Mr. Carruthers' example were followed, it would attended with very great benefit, because railways could be int duced at a much earlier date than they would be if the colonis were forced to adopt gradients of 1 in 45. But although I approved of Mr. Carruthers' gradients, he did not think that t Fell engine was a necessary instrument in carrying out his syste The complexity of the working parts, and the cost of the cent rail, would at once suggest themselves, but there was also anoth objection—the tremendous wear and tear on the centre rail, a on the horizontal wheels running against it. The ordinary ra were only 70 lbs. per yard, so that only 21 tons weight cou be put on the four driving wheels working in a vertical positio Adopting one-seventh as the coefficient of friction, it requir 53 tons pressure to draw up a train of 53 tons and an engine 36 tons, and it followed that since only 21 tons pressure could put on the vertical wheels, 32 tons must be put on the horizont or 8 tons per wheel. That necessitated a centre rail of from 96 l to 120 lbs., or else very great wear and tear on that rail and the wheels. He should like to ask Mr. Carruthers what was t weight of the centre rail, and whether there were any signs flattening in the heads of that rail with such great pressu Mr. Carruthers and Mr. Bruce had said that they would h adopted a wire rope incline, worked by a stationary engine, b they could not find a straight site for it. He agreed that 3 miles a wire rope and a stationary engine would be a v unpleasant affair to deal with, but he did not agree with th gentlemen in thinking that it was necessary to have it straig He had himself constructed an incline with a sharp curve on t lower half of it, at Calstock in Cornwall, in 1871. The idea the system was Mr. Longridge's. Instead of the ordinary ser of rollers between the rails, he had adopted rollers outside t rails on the concave side, two at each point, one roller bei vertical and the other horizontal. The system had worked su ccessfully. The rope, as the engine passed down, was caught the vertical roller, then fell on a horizontal one and lay in t angle. The wear and tear, however, was so great that he could n

recommend the system. The life of a wire rope ⅞ inch in diameter was only three years, and when it was taken up it was found to have a very great number of broken strands, in one instance as many as two hundred in a length of ½ mile. Although he acknowledged the success of the system adopted by Mr. Carruthers in the New Zealand railways, he did not think it was complete. Even with those steep gradients some means were required for carrying up heavier trains. A train of six or eight wagons, such as was commonly seen on colonial railways, drawn by six-wheel coupled engine with a bogie in front, was not sufficient for such work, and it would be still worse where there was a gradient of 1 in 15. It worked so badly even with gradients of 1 in 30 that he knew of a colony where charges from 6d. to 1s. per ton-mile had to be made in order to cover the expenditure and the cost of interest on the construction of the railway; and that, in his opinion, was as bad as a common road, which could be worked from 6d. to 1s. per ton-mile. Facts had already been brought forward to show that much better results could be accomplished by the adoption of other engines. One-seventh was the coefficient of friction between iron and iron, smooth and without sand. Mr. Mosse had stated that he had employed a bank engine on the Kadugannawa incline with twelve wagons, 11 tons each, a brake-van (say 15 tons), and a tender (say 20 tons), altogether nearly 200 tons. That heavy train was drawn by an engine having only 32½ tons of adhesion, giving a coefficient of one-sixth. Mention was certainly made of another engine, which drew the remainder of the train, and he should like to know the weight of that engine and the adhesion. Taking the statement as it stood, the coefficient was one sixth. Mr. Longridge had given, as the result of his experience for several months on the Mont Cenis line, the coefficient of one-fifth, with the use of sand and resin. Mr. O'Meara had taken a mean of one-sixth, and worked out the results for three or four classes of engines alluded to in the discussion. He had taken twelve wagons as a minimum. It was an established maxim that the larger the train the better and cheaper it was. Taking one-sixth, he found that a Fell engine required to be of 75 tons weight. The Fairlie engine of 90 tons would take up a train of twelve wagons. Mr. Longridge's engine would take up a train of twelve wagons with a much lighter rail. With the ordinary 70-lb. rail in use in New Zealand, the train could be drawn by Mr. Longridge's 90-ton engine; whereas the Fairlie engine would require the rails to have a weight of 105 lbs. Mr. O'Mear

Mr. O'Meara. TABLE of WEIGHTS of ENGINES and RAILS required for drawing Twelve Loaded Wagons, or 117 tons, up a gradient of 1 in 15.

Tractive power = $\frac{1}{8}$ weight or pressure on driving wheels.

No.	Description of Engine.	Weight of Engine.	Weight of Rails per Yard.	—
		Tons.	Lbs.	
1	Ordinary six-wheel coupled, with front bogie; $\frac{3}{4}$ of weight on driving wheels	120	210	
2	Fell engine as in use in New Zealand, $\frac{2}{3}$ weight on driving wheels.	75	157½ 157½	Ordinary rails. Centre rail.
3	Fairlie engine, twelve-wheel coupled	90	105	
4	Longridge engine, eighteen-wheel coupled	90	70	

Although the use of curves of 3 chains radius or less was strongly to be deprecated, yet when necessary, Mr. O'Meara thought that an engine on Mr. Longridge's principle, but with four wheels only to each of the front and rear supporting trucks, would best meet the circumstances of the case. Since the Fell engine had proved so successful with six toothed pinions to eight wheels, he did not see why the same number of toothed pinions to fourteen or eighteen wheels should be objected to in the Longridge engine. Were the principle under discussion still further extended to twenty-four wagons instead of twelve, the question of capacity would perhaps be eliminated, and that of saving in construction *versus* saving in locomotive expenses would take its place.

Mr. Sawyer. Mr. E. E. SAWYER, comparing short and steep inclines with longer ones having flatter gradients, said it was not only necessary to consider, as had been so ably done, the character of the engines to be employed, or to point out the advantage gained by concentrating the ascent and shortening the road. A very important point, which hitherto had not been touched upon, was the systems in use for supplying sufficient brake-power for the descent. These varied very considerably on the two systems under discussion, and it would be seen that a railway like the New Zealand had an advantage in this respect, which could not be left out of sight. Its incline was worked solely by special engines; but no additional brake-van was needed, the engine itself being able to apply all the power required to regulate the speed of the train.

To appreciate this advantage more fully he proposed comparing it with the practice on the inclines of the Great Indian Peninsula railway. On this system there were two inclines, namely, the Bhore Ghât, 14 miles in length, ascending about 1,850 feet, and the Thul Ghât, 10 miles, ascending some 850 feet. The steepest gradients in both cases were 1 in 37. According to the official working time tables, every ascending passenger train had four special brake-vans; and every goods train three special brake-vans. There were also two ordinary brake-vans in a passenger train and one in a goods train. The weight of the engine was from 40 to 50 tons; the maximum load with a single engine permitted for a train, exclusive of the engine, was 150 tons; and the weight of a special brake-van was 10 tons. It had been stated that some of these special brake-vans had been so arranged as to accommodate fourth-class passengers; but this did not take away from the fact that so much extra load was put on for the purpose of obtaining brake-power. The number of trains was fourteen each way, of which four were passenger trains. Thus no less than 460 tons of extra dead load were taken up and down the incline daily on account of special brake-vans alone. According to Mr. Rendel's tables, in the returns of Indian railways, it cost on an average ½*d.* to carry 1 ton 1 mile over the Great Indian Peninsula railway system. From station to station the incline was 18 miles long; so that the cost of taking these 460 tons up and down the incline daily at this rate amounted to £34 10*s.* per day, or more than £12,000 per annum. The Thul Ghât was only 10 miles in length, but the number of trains was twenty-three each way daily; so that the cost for moving special brake-vans would amount to the same, or both together to more than £24,000 per annum. The rate of ½*d.*, being the average over the system, was of course much below the mark for the inclines, even allowing for the descent costing less than the ascent. The actual cost incurred by the use of this system of special brake-vans must be very much greater; but sufficient had been stated to show the immense advantage of the Fell, or centre-rail system, where no expense was incurred in taking up and down what was in some degree unprofitable weight.

Mr. Sawyer

The system in force on the Ceylon incline also showed a great improvement on the foregoing. As far as the application of brake-power was concerned, preference was given to ordinary brakes over special brake-vans, except in the case of goods trains, where one brake-van (the weight of which was not given) was employed for an ascending train of eighteen vehicles and a descending train

Sawyer. of twenty-four vehicles. But even this limited use of special brake-vans was an expensive item in the working cost. Taking the special brake van at 15 tons, the number of trains each way at ten, and the cost per ton-mile at 1*d.*, which would not be out of the way, the cost would amount to £15 per day over the 12 miles of incline, and thus to no less than £5,500 per annum.

That special brake-vans could be dispensed with altogether was proved by the fact that a long incline of 50 miles had been worked without them for some years, without a single accident. This incline was on the Mexican railway of 4 feet 8½ inches gauge, having an average gradient of 1 in 40, and for 16 miles a gradient of 1 in 25. Fairlie engines were used, weighing from 60 to 70 tons. They were provided with the Westinghouse air pump and the Le Chatelier brake, and a block on every one of the twelve wheels of the engine. Descending trains consisted of from twenty to one hundred and twenty vehicles, provided with hand-power spindle-brakes and blocks on every wheel of every vehicle. They came down with perfect ease, the engines worked by the Le Chatelier brake, and the blocks either by the Westinghouse brake or hand-power. The wagon blocks were of cast iron, and those of the engines were of wood.

It was strange that none of these inclines were worked by continuous brakes. It could not be from fear of expenditure, as there could be no doubt that the use of special brake-vans was most costly. The idea, he believed, prevailed that the continuous brakes were not adapted to steep inclines. It was said that the brake-power could not be applied gradually; but that descending trains were continually brought to a standstill when these brakes were applied. He believed, however, that Clark's chain brake had been used with success on the Mauritius incline of 1 in 27.

The system of using the same engine as far as possible, and only using a bank engine to help, as in force on the Ceylon incline, was also very superior to the system of working entirely with special engines. There could be no doubt that, whenever possible, the system of adopting one class of engine to work the line throughout should be aimed at, even should it necessitate a greater outlay at first. If special engines were necessary, it then became a question whether concentrating the ascent by the adoption of steeper gradients for such a system as the Fell was not preferable; more especially when it held out, as had been shown, such an advantage in economy of first cost and working.

Berkley. Mr. G. BERKLEY said that about two months ago he was taken 7,000 feet above the sea, on Mount Washington, by a railway

similar to the Rigi railway. He would not attempt to describe it, but would simply express his concurrence with the remark of Mr. Bruce, that in the case of such a railway there should be either a rock or other perfectly solid foundation. He did not agree with a previous speaker in thinking that the two Papers should have been read separately. He considered that they had been judiciously combined, and that the question raised was a most important one, viz., the best method of laying out lines in the colonies. With regard to the New Zealand railway, Mr. Carruthers, a most competent authority, had stated that no one who knew the circumstances of the country could doubt that the right thing had been done. For himself, he was of opinion that it was "not proven" that the plan there adopted was the best for a railway 400 miles in length, and for traffic which, though not large, would be constantly increasing. He thought it probable that the throttling of the traffic by the incline of 1 in 15 and the introduction of a special and complicated system of working might ten years hence be discovered to be a mistake. The step taken by Mr. Carruthers of introducing a steep incline on the line had been ably supported by Mr. Longridge; but Mr. Berkley demurred to that gentleman's calculations, because he had distinctly stated that they were not based on accurate sections. Figures were the most deceptive things one could possibly deal with unless they were absolutely true and correctly applied to the circumstances under consideration. He agreed with everything that had been stated by Mr. Gregory on this subject, and he would add nothing to it except to impress on the members some points as the results of his own experience. First, if there were steep gradients, even of 1 in 40, they should be divided into short lengths by intervening portions of "level" or easy gradient. Secondly, a shorter radius of curve than could be avoided should not be adopted; because, although the resistance of curves might not be so great as that of gradients, the wear and tear arising from them and the consequent necessity for putting the engines into shed for repairs were serious inconveniences in working the traffic. Thirdly, a railway should be made as capable as possible, and not limited to the existing requirements of the traffic. To that end two causes of resistance should never be combined—the ruling or shorter radius of curve and the ruling or steepest gradient—at the same point. Mr. Berkley.

Mr. LONGRIDGE remarked, in explanation, that his calculations with regard to the Mauritius railway and the Midland railway from Derby to Leeds, were based on the actual sections of those lines. In the latter case, though he had not accurate sections, he Mr. Longridge.

Longridge. was satisfied the results he had given were substantially correct, and would be borne out by experience in such a country as was referred to.

r. Barlow. Mr. W. H. BARLOW, President, said it appeared to him impossible to inculcate any general laws for the laying out of railways such as those described in the Papers. There were dominant circumstances which must control them. It was so even in England. On a part of the railway with which he was most intimately concerned, the Midland, there was an incline of 1 in 37 which had been made for many years and had a large traffic over it, and on other parts there were gradients of 1 in 120. The company had been spending large sums of money in improving the gradients on 1 in 120, while they had not felt it necessary to improve the gradient of 1 in 37. That showed that the circumstances of the traffic might regulate such matters as well as the circumstances attending the construction.

Correspondence.

Mr. Abt. Mr. R. ABT would compare the conditions of the line from Wellington to Woodville with those of two similar lines, one of which was worked by an ordinary tank locomotive, while the other was a rack railway. The first of these, the Uetliberg railway, was fully described in the foreign abstracts.[1]

The second was the Rorschach-Heiden railway. Rorschach was a main station of the United Swiss railways, on the shores of the Lake of Constance, 1,320 feet above the sea. Heiden, 2,600 feet above the sea, was a well-known pleasure resort. The railway between the two had to facilitate the journey of visitors to Heiden, and at the same time to serve a good many quarries situate near the middle of its length, at the Wienachten station. It had been open since 1875. The trains were made up on the quay at Rorschach, and first ran for about 1 mile over the track of the United Swiss railways. This part was nearly level, and had only a few curves, of large radius. The incline was 3 miles 188 yards long. The steepest gradient was 1 in 11; the curves were generally of 600 feet radius. The gauge was 4 feet 8½ inches, as the goods wagons of the other Swiss and French railways had to pass over the line as far as the quarries at Wienachten. The rails were 3½ inches high, and weighed 40 lbs. per yard. The wooden cross-sleepers were spaced 2½ feet apart. On the centre line of the railway was a rack, exactly like that on the Rigi.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xl., p. 275, and vol. xlix., p. 307.

Mr. Abt.

The railway was worked by three rack-wheel locomotives, built at the late engine works at Aarau. At first the level part of the line, from the quay at Rorschach to the foot of the incline, was worked by adhesion-locomotives of a special type. But as the line had a very small traffic, and this arrangement greatly increased the expense, in 1878 the rack-locomotives were modified, so that, by the help of the adhesion of one pair of wheels, they could run on the ordinary rails, without a rack, to the quay. The principal dimensions of these locomotives were as under:—

Diameter of cylinder, 11·8 inches; stroke, 20 inches; boiler pressure, 150 lbs.; grate surface, 10¾ square feet; heating surface of fire-box, 62 square feet; ditto of tubes, 475 square feet; total, 538 square feet: weight empty, 12¾ tons; with fuel and water, 16½ tons; wheel base, 10 feet; diameter of travelling wheels, 32½ inches; of the rack-wheel, 41 inches.

There were seven carriages for summer traffic, weighing 214 lbs. for each seat; and two for winter traffic, heated by steam, weighing 482 lbs. per seat; giving 414 places in all. All the carriages had brakes for the rack-wheel. The railway possessed only eight goods wagons of its own, weighing each about 4 tons, and carrying about 7½ tons. The cost of the railway, including materials, was £90,000, or £25,664 per mile; which sum, considering that the difficulties of construction were moderate, seemed extraordinarily high.

The normal capacity of the engines, very seldom utilised, was to draw a train of 39 tons (exclusive of the engine) at a mean speed of 5 to 6 miles an hour in ascending, and 6 to 7½ miles in descending. The expenditure of coal was 53 lbs. per train-mile. The whole working expense per train-mile was 4*s.* 2*d.*, of which 2*s.* was for running expenses.

A comparison of the performances on these two lines with that on the Featherston incline gave the following:—

Railway.	Load Drawn on Incline of 1 in 15, exclusive of Engine.	Average Weight of Locomotive.	Load Drawn per Ton of Locomotive Weight.
	Tons.	Tons.	Tons.
Wellington and Woodville . . .	64	36·0	1·8
Uetliberg	26	23·5	1·1
Rorschach and Heiden	58	15·5	3·7

The speed on the Uetliberg railway (9½ miles per hour) was about twice as great as on the other two lines. The work done,

Mr. Abt. considering that it was a simple adhesion system, was large; the other hand, the safety was certainly less than with the Fel rack systems. The first cost and the working cost must, howe be less with the simple system. The working cost for such s local lines was not really comparable with that on main li because it depended on so many different circumstances. Th was a decided difference between the results of the two spe systems, the Fell and the rack railway. On an incline of 1 in the rack locomotive, weighing 16·5 tons, drew almost as muc the Fell locomotive, weighing 36 tons. Mr. Abt would under from actual experiment, to build a locomotive of about 16 t which on an incline of 1 in 15 should draw, besides itself, a l of 70 to 75 tons, or 4½ times its own weight, at a spee 5 miles per hour.

The permanent way for rack railways consisted, besides rack, of exactly the same pieces as for an ordinary railway. rack and its fastenings cost at present 21*s.* per lineal yard, or, laying, 22*s.* 6*d.* to 22*s.* 9*d.* Probably it would cost slightly m than the central rails and their fastenings of the Fell syst The safety, however, with the rack system was higher than the other, especially in bad weather and with much snow. rack engines of the "mixed system," which were built by Mr. at the Aarau works, possessed equally with the Fell engines power of moving, both on the rack by the rack-wheels, and ordinary lines by adhesion; but the speed in the latter case only a little higher than on the rack. Since this problem been satisfactorily solved by rack engines on the mixed sys and several engines had proved thoroughly satisfactory in work he believed that in most cases, where the introduction steep incline was needed, its working by rack railway would much more advantageous than by the Fell system. The itself, after ten years' service, showed not the slightest wear; expense of lubrication (2·46*s.* per mile of track per annum) not worth mentioning. Again, the expense of lubricating special rack-gear was small, say one-third the average cost ordinary working parts. The heaviest expense was that of m taining the gear itself. The large rack-wheel cost about and would run 30,000 miles before it needed changing. The in mediate wheels cost together £80, and would run 50,000 miles

Alford. Mr. R. F. ALFORD had been engaged in designing the Fell engi under Mr. Widmark, at the Avonside Engine Company, and, thr the courtesy of the consulting engineers for New Zealand and manufacturers he was able to submit the following informatio

Mr. Alford.

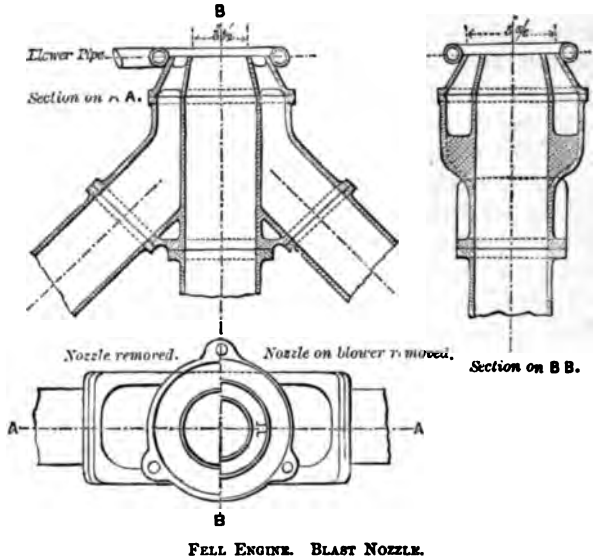
In the first place, a slight error had crept into the Paper as to the stroke of the inside or Fell cylinders. They were not 12 inches in diameter and 15 inches stroke, but 12 inches in diameter and 14 inches stroke. This altered the tractive force from 96 lbs. to 89·6 lbs. per lb. of effective steam in the cylinders. The weight of the engine had been also stated slightly high; the weight empty being 27¼ tons at Bristol; there had been a slight alteration in the cab, but this could not add more than 2 or 3 cwt., which gave a total weight of 30¾ tons and 34½ tons in running order, with the tanks and coal-boxes empty and full respectively, and a calculated weight of 25 tons 8 cwt., 26 tons 6 cwt., and 27 tons 3 cwt., on the coupled wheels, with the tanks empty, half full, and full, respectively. The calculated adhesive working pressure due to the four Fell wheels was 26 tons 6 cwt., or 13 tons 3 cwt. on each side of the rail, giving 6 tons 11½ cwt. per wheel; but more or less pressure could be put on if thought desirable, and at a trial of one of the engines at Bristol the Fell wheels drew the engine backwards with full steam on both engines; the tanks and coal-boxes were filled, so as to give the highest possible adhesion to the coupled wheels of the ordinary engine.

The above pressure on the Fell wheels was due to a pressure of 17½ tons on each of the compression springs, which were of the ordinary crescent shape, and consisted of nine plates 6 inches wide by ⅝ inch thick. The pressure on each pair of distance discs was 4 tons 7 cwt., being 2 tons 3½ cwt. on each disc, and it was thought that this would be sufficient to keep the spur wheels in gear. The studs mentioned by Mr. Carruthers were only put in as an extra precaution; but it appeared from actual practice that the pressure should have been greater, to prevent the wheels parting; this could be easily arranged in a future design by putting the springs slightly higher.

With regard to the remarks of Messrs. Carruthers and Longridge on the steaming, it was very satisfactory to hear that, with the occasional use of the blower, steam could be easily kept up for the four cylinders, notwithstanding the disadvantage arising from the tunnels, when it was remembered that the heating surface of the fire-box was only 75 square feet, and of the tubes 783 square feet, which was arranged for a pressure of 130 lbs., instead of 150 lbs., and to draw a load of 50 tons, exclusive of its own weight, as against 63 tons, which it had actually taken. This increase in the pressure of steam by nearly 15½ per cent. accounted for the tractive force being greater than the adhesion. The blast was arranged as shown in the sketch (Figs. 3, 4, 5), the inside nozzle

r. Alford. took the blast for the Fell cylinders, and the annular ring for the ordinary engines. The area was respectively 11·3 square inches and 12·3 square inches, which was about one-tenth the area of the cylinders; and it appeared probable that by putting a new nozzle so as to give a sharper blast, the use of the blower might be dispensed with. It would be seen that by the above arrangement of blast the two engines worked independently of each other, and

FIGS. 3, 4. FIG. 5.



FELL ENGINE. BLAST NOZZLE.
Scale 1 inch = 1 foot.

could not give rise to the evil results described by Mr. Longridge in the engines he had experience with, and which were certainly quite different in many points from those mentioned in the Paper. The latter were by no means blind copies of any previous engine. In these engines the sand was thrown between the rails and vertical wheels by a jet of steam, with a kind of injector: perhaps it would have been better to have used a blast of air. In reference to the cost of working the line, the four engines were contracted for at a cost of £3,625 each, delivered f. o. b. London, not including duplicates. The contract was let in the autumn of 1874, when prices were very high.

Bergeron. Mr. C. BERGERON would, at the outset, state his opinion that the working of mountain railways, although more costly than that of

ordinary lines, was capable of being effected with regularity, when the inclines did not exceed 1 in 40. For eight consecutive years the Franco-Suisse line between Neuchâtel and Pontarlier, having a gradient of 1 in 50, had been worked at a cost not greater than 60 per cent. of the gross receipts, which reached 20,000 francs per kilomètre (£1,280 per mile). Mr. Bergero

In the surveys now being made by the engineers of the French Government in the departments traversed by mountain ranges, the limit generally imposed for curves, was a radius of 300 mètres (say 1,000 feet), with a maximum incline of 1 in 40. Mr. Bergeron could not say what modifications were made in the above data when narrow-gauge lines were in question. Such lines would evidently allow of large reductions in these figures, to the extent of 100 mètres for curves and 1 in 25 for gradients. In 1863–64 Messrs. Le Haître and Mondésir made complete surveys for the passage of the Simplon, by inclines of 1 in 25, and as they could not find the means of traversing all the small valleys in ascending the Saltine, even by making reverse curves, they proposed zig-zags (*rebroussements*). Their project was approved by the General Council of the French Ponts et Chaussées, and by the technical commission of the Swiss Federal Council, and by the engineers of the Canton du Valais; but the company was never able to find the necessary capital for this railway, and soon after itself failed.

Mr. Bergeron had several times traversed the line from Modane to Susa, established on one side of the high road over Mont Cenis. He had found in Mr. Fell's system an excellent expedient for reassuring the passengers, and the centre-rail, solidly attached to the sleepers, afforded every security against derailment, and the deepest and most abrupt precipices were passed without exciting the least fear.

The locomotives were complicated. They frequently got out of order. He should always remember one occasion, on which Mr. Brassey, who had embarked a large capital in the enterprise, had assembled his friends, of whom he was one, to exhibit to them the advantages of the system, by carrying them over the whole line, from Modane to Susa. One after another three new locomotives were tried, and each got incapacitated for drawing the train. By degrees improvements had been made in the engines, and at length the service was able to be carried out regularly. The company did not, however, long enjoy the exceptionally high tariff conceded to it. A few years after it was at work, the great tunnel made by Messrs. Sommeiller and Grattoni was completed, and the day after its formal opening, the removal of the

ergeron. mountain line began. He believed that since then not the least attempt had been made to apply the Fell system to other mountain lines in Europe. He had been several times struck to see the four vertical driving-wheels of the engine haul the train through its entire journey over the steepest inclines, notably that encountered on leaving Modane, without other assistance than the adhesion due to its own weight. That occurred in very dry weather, when there was no slipping, and he had wondered why the horizontal driving-wheels were not replaced by additional vertical ones, arranged as in the Fairlie engine, or on a plan even more efficacious, devised by Mr. Longridge, which it was to be regretted had not been tried on the Mont Cenis line.

At the present time, Mr. Bergeron had other ideas for the establishment of mountain railways. He believed they should be made on the system of a canal in which the level reaches were interspersed with locks, represented in the case of railways by inclined planes. With a railway with inclines not exceeding 1 in 100, and locomotives powerful enough to haul the trains of passengers and of merchandise habitually circulating over the whole of its extent, he would desire that the trains should further be able to cross mountains without additional engine power, of which the employment was always onerous and the cost very high, not only on account of the greater power of the bank engine, which must be always very heavy to ensure adhesion, but also on account of the extra wear of rails and tires due to the application of the powerful brakes necessary for the safe descent of the inclines. He would therefore not hesitate to adopt 1 in 100 as the limit for sections of mountain lines, adopting inclined planes at different points, like the flights of stairs in houses. For example, supposing he had to cross a mountain range by a line having, as in the case of the Simplon, a summit level 1,000 mètres above the station at the foot of the mountain, he would, as nearly as practicable, divide the length of say 20 kilomètres into sections of five 4 kilomètres each. These sections, being inclines of 1 in 100, would themselves afford a total vertical rise of 200 mètres, and each inclined plane should be surmounted by means of apparatus worked by the torrential streams always at hand in great abundance to the extent of several thousands of HP. By fixed engines on the Agudio[1] system, by atmospheric tubes as employed at Saint Germains, by apparatus of the nature tried by Mr. Louis Gonin at Lausanne, by cables and fixed engines as now employed at several places, notably at Lyons

[1] *Vide* Minutes of Proceedings, Inst. C.E., vol. lx., p. 310.

and at Lausanne, it would be easy to haul up an incline plane a train and engine complete, and ready, when at the top, to proceed in the usual manner. He would use the same apparatus to control the trains when descending the inclined planes. By this means the passage of mountains might be effected at small cost, seeing that nature would supply the additional power, and the only expense would be that of installing the apparatus and of applying it when required. Where there were no waterfalls, fixed steam-engines could be employed with advantage. In all cases they would be worked much more economically than the bank engines, always necessary for inclines of 1 in 20 or 1 in 25. Mr. Berger

Mr. G. FISHER submitted the following particulars of the working of the old incline at Aberdare junction. The gradient was 1 in 21 for 22 chains, and 1 in 18 for 17½ chains. The engines used had cylinders 16 inches in diameter, with a length of stroke of 24 inches, and wheels 4 feet 2 inches in diameter, and were worked to a pressure of 120 lbs. per square inch. The weight of the engine in steam was 36 tons, the consumption of fuel being about 42 lbs. per mile. The maximum load, exclusive of the engine, was 50 tons. The company altered this incline in 1868 to 1 in 40; but another incline, on the Clydach Vale branch, with a gradient of 1 in 30, was at present being worked with engines of the same type as the above, the maximum load, exclusive of the engine, being 70 tons. Mr. Fisher.

Mr. D. M. Fox fully concurred in all that had been said as to the futility of attempting to lay down hard and fast rules for the surmounting of steep and lofty mountain ranges by railways, or of maintaining that any one system was the best possible, and ought invariably to be adopted. It might, however, be taken as an axiom that, where the mountain range to be traversed lay at right angles to the direction of the railway, so that every mile of development on the ascent or descent lengthened the distance by a deviation directly in proportion to the flatness of the inclination, then short inclines with steep gradients should be adopted; and, conversely, where the range to be crossed was parallel, or oblique to the direction of the railway, so that the development necessary to obtain flat gradients on the ascent or descent did not practically lengthen the line between fixed terminal points, then the most favourable gradients that could possibly be obtained should be adopted. The map showing the direction of the New Zealand Government Railways represented the Rimutaka range as running obliquely to the direction of the line from Wellington to Featherston and Napier, and it would appear that there had been Mr. Fox.

Mr. Fox. little or no saving in distance by the adoption of the steep inclin unsuited to ordinary locomotive traction. Still, if the Rimutak were so exceptionally rugged and precipitous, that on the descen of their eastern slope a gradient of 1 in 40 would have involve such a "dangerous and impracticable" line—"a succession curves chiefly of 3 chains radius, often reversing on the sam point, and many embankments 100 feet deep at the centre line"· then it must be admitted that the chief engineer acted wisely adopting a steep gradient. In such a case Mr. Fox would ha endeavoured to lay out inclines on the "fixed engine and rop system; but, as it was stated in the Paper that this had be attempted, but without success, it need only be remarked th perhaps a suitable location for steep inclines to be worked by fix engines was not found, because it was assumed that such inclin must necessarily be laid out in straight lines, whereas with gauge of 3 feet 6 inches curves of 10 chains radius would ha been worked with ease with fixed engines and ropes on an incli of 1 in 10. Nearly fourteen years of practical experience the working of the Serra inclines of the São Paulo (Brazilia Railway, with gradients of 1 in 10 and fixed engines and ro had convinced him that, where it was impossible to obt gradients suited to the ordinary locomotive, the old-fashio plan of fixed engines and ropes was to be preferred to centre rail or Fell system, or to the rack and pinion or F system, or to any other device by which it was sought force the locomotive to do work for which it was not adapted. a Paper which he had written, "On the Line and Works of São Paulo Railway, Brazil,"[1] a full description of the incli planes on the Serra do Mar, and the mode of working the incli had been given. It was satisfactory to be able to record t these inclines, surmounting a height of 2,560 feet in 5 miles, worked by fixed engines and ropes, had been open and work for nearly fourteen years, both for passengers and goods, with an accident attributable to the system of traction employed, to note that the anticipations of the engineer-in-chief, Mr. Ja Brunlees, Vice-President Inst. C.E., had been more than reali Such was the simplicity and durability of the stationary engi that the traffic had never been delayed an hour by repairs, and original brasses were still in use. The steel wire ropes had t made to last three to four years, running from 20,000 to 30, miles before being taken off. The safety or clip brake had t

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxx., pp. 36, 41.

efficient in working. Although the line was originally laid out with no curves of a sharper radius than 30 chains, a serious land-slip which occurred in 1872 rendered it necessary to divert it, and reverse curves of 15 chains radius were employed in order to avoid the reconstruction of an enormous embankment that had been carried away. These curves had ever since been worked with ease and safety, so that no attempt had been made to reconstruct the embankment. An electrical signal had been devised by which communication could be made with the driver in the engine-house by the men on the safety brake-wagon without their leaving the brake. The trains were limited to three wagons or cars and the special brake-wagon to which the rope was attached; and it was the great advantage of this system of traction that not only was the dead weight to be lifted reduced to a minimum, but that a train was raised and lowered simultaneously, thus economising power and time. As from four to five trips could be easily made in the hour, it followed that twelve to fifteen wagons (each carrying, say, 7 tons of paying load) were raised and the same number lowered per hour. Thus, 80 to 100 tons of paying load could be raised and the same weight lowered per hour, making a total of 600 to 800 tons each way, or 1,200 to 1,600 tons of paying load of up and down traffic per day of eight hours. And in fact as many as 8,500 bags or 500 tons of coffee alone had descended the Serra inclines and been placed in Santos with ease. But it must not be supposed that the preponderance of the traffic was down or export traffic. He was enabled to give the following Table showing the tonnage carried over the São Paulo railway for the week ending the 31st of October, 1880, taken from official returns:— Mr. Fox.

Description.	Down.	Up.
	Tons.	Tons.
Coffe	1,694	..
Cotton	18	..
Salt	..	478
Sugar	..	317
General	43	..
„	..	1,263
Bricks, lime, &c.	144	200
Coal	..	547
	1,899	2,805

Giving an average daily traffic for the six working days of 316 tons down or export, and 467 tons up or import traffic. On the São Paulo railway there was no throttling of the traffic by the inclines, whatever might be the case by the employment of the Fell or any

Mr. Fox. other abnormal locomotive system. On the contrary, the incl were capable of accommodating up and down the Serra as n traffic as could be carried on the single line of railway of w they formed part.

The annexed Table showed the average daily cost of wor the ordinary traffic over the Serra inclines. The averages, of traffic and of expenses, had been compiled by him from of sources, and were taken over a period of two and a half years. would be interesting to calculate what would be the approxi cost of working such traffic with a gradient of 1 in 15, and the centre rail system. He ventured to affirm that the cost w be considerably in excess of that showed. In the discussio the Paper read by him on the São Paulo railway, in March 1 Mr. Brunlees observed that, "had a similar work to be undert now, he would probably try to get a gradient of 1 in 14, employ the centre rail system."[1] Mr. Fox, however, consid that the fourteen years' experience of the working of these incl planes proved that it would have been a mistake, under the sp circumstances and conditions of the case, to have adopted other system than that of fixed engines and ropes for the mounting of the Serra on the São Paulo railway.

SÃO PAULO BRAZILIAN RAILWAY.

AVERAGE DAILY COST of WORKING the SERRA INCLINES of 1 in 10 (FIXED EN and ROPES). Also AVERAGE DAILY TRAFFIC CARRIED UP and DOWN.

Gradient 1 in 10. Number of inclines, 4. Length of inclines, 5 mile Height surmounted, 2,560 feet.

Average number of trains per day	.	passenger	up	3	
" " "	.	"	down	3	
					— 6
" " "	.	goods	up	13·5	
" " "	.	"	down	13·5	
					—27
Total average number of trains per day					33
Average number of cars and wagons per train (without brakes)					3
" " passenger cars per day .				6 × 3 =	18
" " goods wagons " .				27 × 3 =	81
Total average number of cars and wagons per day					99

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxx., p. 57.

Mr. Fox.

	Tons.
Average weight of trains, gross, 3 passenger cars with load . . . . } say	20
„ „ „ 1 special brake . . .	6
Total average weight of passenger trains . . .	26

	Tons.
Average weight of trains, gross, 3 goods wagons with load, of 5 tons . . . . }	27
„ „ „ 1 special brake . . .	6
Total average weight of goods trains	33

	Trains.	Tons.	Tons.
Total average gross weight, raised and lowered 2,560 feet . per day	Passengers	6 × 26 =	156
	Goods	27 × 33 =	891
			1,047

Trains. Tons.
Or, deducting special brake 33 × 6 = 198 tons,
1,047 tons less 198 tons = 849 tons gross weight per day.

Train-miles.
Average number of train-miles per day . . 33 × 5 = 165

	£.	s.	d.
Average coal consumed per day, 5·75 tons . . .	10	7	0
„ oil, tallow, and other stores	1	5	0
„ salaries and wages for running	11	6	4
Total average daily cost, running . . .	22	18	4
Average repairs, including engines, ropes, pulleys, &c.; wages, and stores, per day . . . . . }	6	17	4
	29	15	8
Average proportion of cost of carriage and wagon repairs, per day . . . . . }	1	7	0
Average proportion of cost of maintenance way and works, 5 miles, per day . . . . . }	5	10	0
Total average daily cost, over a period of two and a half years . . . . . }	36	12	8

Mr. A. Gottschalk, President of the Society of Civil Engineers of France, would confine his observations to the gradients of 1 in 15 and 1 in 44. In the first case he remarked that the usual working load of the Fell engine, weighing 36 tons, was 56 tons gross, or a proportion of 1 to say 1·55. The Riggenbach engines hauled about the same weight, or rather more upon the same gradient of 1 in 15 with an 18-ton engine, the proportion being thus 1 to 3·11. For such gradients he was in favour of the Riggenbach system. The rack, no doubt, rendered the first cost rather greater than the simple rail of the Fell system, but the Riggenbach engine was much simpler, the brake much more powerful, and the safety was absolute. For gradients less steep than 1 in 20 or 1 in

Mr. Gottschalk

ttschalk. 22, he thought the best and cheapest way was to use ordinar engines. In the case of the Kadugannawa incline, 1 in 44, h was of opinion that the ordinary goods engine, with four-couple wheels, 5 feet in diameter and a bogie, was not the best. Th weight was 35 tons. Such an engine, placed at the rear of th train, pushed six loaded wagons of about 11 tons each and a brak van, say 76 tons. Under the same conditions, but for an inclin of 1 in 40, his last six-coupled engines hauled 150 tons, the weigh of the engine in working trim being from 41½ to 42 tons. . description of this engine would be found in the "Mémoires" (the Society of Engineers of Paris, 1878, p. 440 (abstracted i Minutes of Proceedings Inst. C.E., vol. liv., p. 315). It would b noted that this engine was much more in accordance with th described in Mr. Mosse's Paper as a bank engine, weighin 35 tons, and hauling twelve wagons and a brake-van. He b lieved that for such gradients (1 in 40 to 1 in 44) it was bett to have only one type of engine for both passenger and freig trains, especially when the line was first opened. The engi should have six-coupled wheels, not more than 4 feet in diamet without any bogie. The weight would vary with the nature the traffic, but might reach 7 tons per wheel. Such engines, bei of the latest type introduced by him on the Brenner incline, co haul passenger trains of from 120 to 130 tons at 14 miles an hc and of 150-ton goods trains at 9 miles an hour. This was experience of twelve years in working the Semmering and Brenner inclines on the Southern Railway of Austria.

Mr. Mac-dougall. Mr. ALAN MACDOUGALL considered the circumstances un which the Government railways under discussion had been c structed were peculiar, and not likely to occur on many tr lines. For the opening up and colonization of a new country considered the excessive gradients on the New Zealand railw would prove rather a drawback. The subject of steep gradi had been anxiously considered in Canada on many coloniza and private railways, and much adverse criticism had b directed against Mr. Wragge, M. Inst. C.E., when he introdu a gradient of 1 in 50 on the Toronto, Grey, and Bruce railv Still this gradient, which was only for about 3 miles in length, not proved obstructive to that company's traffic. At the to this incline, known as the Caledon incline, were two semicirc curves of 500 feet radius, joined by a short straight portion fo ing an S, the gradient here being about 1 in 70. Severe as strain was to pass round these curves on the ascent, the difficul were not so great as in passing round the succession of sh

Mr. Macdougall.

verse curves in the valley of the river Humber, about 18 miles rom Toronto, where the gradients were 1 in 60 and 1 in 70, the adii of the curves being from 462 feet to 500 feet. This was ound to tax the locomotive power so severely, that he understood t was contemplated to amend the location of this portion of the ystem when the gauge was widened. Mr. Sandford Fleming, .M.G., M. Inst. C.E., had given the subject of sharp curves and teep gradients his careful attention in laying out various lines f railway. On the Canada Pacific the gradients would not be teeper than 1 in 100, except only in a few places on the Rocky Mountain range, where gradients of 1 in 50 would be permitted, with curves of about 1,400 feet radius. Curves and gradients, similar to those used on the Ceylon railways even, would render a line passing through a snowy region inoperative for the whole winter season. He thought it was a great pity that the Authors of the Papers under discussion had not attempted to give some statistics of the growth of the colonies in question, and the increased value of assessments in consequence of the construction of these railways. He was keenly alive to the difficulty of obtaining statistics in a young country; still, he thought persons in the prominent positions of the Authors of the present Papers, and of several others which had lately been before the Institution, could have obtained some figures bearing on the subject. He had much pleasure in giving a few facts connected with the progress of some of the western counties of the province of Ontario, Canada, since the introduction of railways into them. The counties of Grey and Bruce were without railway accommodation, and Wellington and Simcoe were partially accommodated by railways in 1869.

Name of Counties and Cities.	Value of Assessments (Real Estate).			Increase between 1869–1879.
	1859.	1869.	1879.	
	$	$	$	Per cent.
County of Grey	10,320,000	11,670,000	13,706,876	17
„ Bruce . . .	3,506,811	7,891,217	24,485,336	210
„ Simcoe . . .	5,831,888	11,702,285	16,975,371	45
„ Wellington, including City of Guelph .	6,601,170	9,863,687	35,330,568	258
City of Toronto	..	19,162,205	41,212,757	115
„ Hamilton . . .	700,937	6,781,161	15,223,269	124
„ London	3,916,266	5,245,780	8,928,365	70

Mr. Macdougall. The City of Toronto was included in the assessment of County of York in 1859. The City of Guelph here included the County of Wellington, was separated from it in 1879, as figures could be obtained for 1869.

Mr. Manning. Mr. J. R. MANNING, in regard to the system of conducting traffic over the Bhore and Thul Ghât inclines of the great Ind Peninsula railway, explained briefly the circumstances which the time, necessitated the adoption of the present system working. It had been stated that the traffic on the Ceylon other short railways was safely and more economically worked independent brakes attached to each vehicle, without the ai special brake vans, and that there was no apparent reason a similar system should not be adopted on the Bhore and T Ghât inclines, and the use of special heavy brake vans abandon

The theory that each vehicle should be provided with i pendent brake power was no doubt sound, and for short line railway in mountainous districts, like the Ceylon and otl which consisted of steep gradients almost throughout their e length, the system of working adopted was doubtless econon and safe; but, on the Great Indian Peninsula railway, the Bhor Thul Ghât inclines were respectively only about 14 and 10 long, or less than 2 per cent. of the total length of the rail which was 1,300 miles in length. Shortly before the opening o railway, numerous discussions had taken place between the l of departments of the railway and the Government officials, the best method of working the ghât inclines, and it was mately decided, that it was more advisable to employ sep special brake power than to fit up and maintain, in effi working order, the rolling stock of the whole system with pendent brakes sufficiently powerful to be safe on the g Owing to the length of the railway, it was not unusua numbers of vehicles to be employed in local traffic, and pe for months together they would not be required to pass ove incline. When they were required to do so, the probal would be, that, owing to the nature of the work on which had been employed, and to the mere superficial examinati which they had been subjected, the brakes would be out of c and the vehicle rendered unsafe. Under such circumstances would be a delay while the brakes were being put right, o contents transferred to another vehicle. Another important r for the adoption of the present system of brake power, wa fact that a large number of vehicles, belonging to other rai companies, often passed over the ghâts, some of them unpro

with brake-power of any description. During the late famine in India, it was not unusual to see whole trains of foreign vehicles on the ghâts, without a single independent brake. With such a constant interchange of rolling stock it had, up to the present time, been thought useless for the great Indian Peninsula Railway Company to fit up its own vehicles with self-supporting, independent brakes, unless other railway companies would do so also, which they could hardly be expected to do, considering brakes of the kind were not needed on their own lines. The dead weight, or non-paying load on the ghâts, was not very great, inasmuch as the incline brake vans were fitted up and utilised as carriages, into which fourth and, sometimes, third class passengers were transferred at the top and bottom of the ghâts. Although satisfied that the system of working the ghât inclines had hitherto been the best that could be adopted under the circumstances, he thought that, looking at the great improvements in brake power which had been effected during the last few years, the time had arrived when continuous brakes should be employed; and the adoption of which, he understood, had been already recommended by the consulting engineer. Mr. Mannin

Mr. J. MORANDIÈRE remarked that in France the working expenses of irregular lines, when belonging to the great companies, were extremely difficult to get at, owing to their not being separated from the general accounts. Thus, in the case of the Western railway, there was, 1st, the St. Germains incline, from Pecq to the St. Germains terminus, of which the gradient was 1 in 28, at first worked on the atmospheric system, but for many years past by 6-coupled locomotives weighing 39 tons each; 2nd, The Fécamp incline, between Fécamp and Ifs. This latter, on the Beuzeville Breanté branch, had a gradient of 1 in 58, but the accounts of neither section were kept separate, so that the effect of the inclines on the cost of working could not be ascertained. Mr.Morandi

He was able to append some particulars of the Enghien and Montmorency railway, furnished him by the company's manager, Mr. Level. The line was 2,872 mètres (about $1\frac{3}{4}$ mile) long, of which 1,297 mètres were straight, 320 mètres curves of more than 25 chains radius, and 1,255 mètres curves of less than 25 chains radius. Of the profile 303 mètres were level, 200 mètres rose 1 in 200, 1,331 mètres 1 in 50, and 1,037 mètres 1 in 24. The rails were of steel of the Vignoles type, weighing 60 lbs. per yard. Oaken sleepers were used as on the Northern railway. The line left the Enghien station of the Northern of France railway near Paris, and used the terminus at Enghien with that railway.

Morandière. Midway between Enghien and Montmorency was the Soisy station for passengers only. There were five level crossings, at two of which were watchmen's cottages; three were merely provided with safety gates. Near Soisy was a branch, 225 mètres long, to a plaster quarry. During the construction of the Domont, Montlignon and Montmorency forts, the contractor made use of an inclined plane starting from one end of the Montmorency terminus and leading to the high ground. Some particulars of the cost of working, which amounted to 67 per cent., would be found in a report to the shareholders of the company, dated the 24th of April, 1880, a copy of which he had the pleasure to present to the library of the Institution, in Mr. Level's name.

Mr. Riggenbach. Mr. N. RIGGENBACH, late locomotive superintendent of the Central railway of Switzerland, furnished a pamphlet descriptive of his toothed-wheel locomotives, some of them exhibited at the Paris Exhibition of 1878. These were of two kinds, viz., engines for working on the rack system only, and for working either by rack or by adhesion. At the Paris Exhibition two kinds of the latter had been exhibited, viz., *a* and *b*. The locomotives for working on the rack system only, employed on the Rigi, on inclines of 1 to 4, were too well known for being exhibited; they hauled a train of the same weight as themselves at a speed of 4 to 6 miles an hour. In the exhibited type *a* the carrying wheels were controlled by the toothed pinion, which was from two to two and a half times smaller, the speed could not therefore be greater than 9½ miles an hour. This type, which was of very simple construction, was best adapted for mines or quarries, or to connect such places with an ordinary railway station. The gauge could be either broad or narrow; the weight of the engine, all found, would vary from 10 to 18 (metric) tons; they would draw up inclines of 1 in 20 a train five times their own weight, and on 1 in 14 of three times their own weight, at a speed of from 4 to 6 miles an hour. The exhibited type *b* would run at any speed as on an ordinary railway, the driving wheels being directly attached to the connecting-rods. Each driving axle, however, was furnished with two loose wheels or pulleys, which acted as carrying wheels when the engine was on the rack incline, the latter being provided with two inner rails corresponding with the small wheels. By this means the train could leave the ordinary rails and enter the rack incline without stopping.[1] These engines were made for

[1] This proceeding is described in detail in the abstract on the tramway at the Laufen quarries, vol. lvii., p. 346

either broad or narrow gauge. Their weight, ready for work, varied from 5 to 18 tons. The 7-ton engine would haul a train of 40 tons, besides its own weight, up inclines of 1 in 100 at 16 miles an hour, and 20 tons up 1 in 33, using the ordinary driving wheels. With the rack, 20 tons could be taken up 1 in 14 at 6 miles an hour. All these locomotives were provided with compressed-air brakes of a special type devised by Mr. Riggenbach, no ordinary skidding brake being capable of controlling such weights on the inclines mentioned. Mr. Riggenbach.

Mr. Riggenbach also supplied an account of the first rack railway constructed in Prussia, a description of which will be found in the Foreign Abstracts, *post* p. 386.

Mr. JOHN ROBINSON, of East Grinstead, remarked that a railway with excessively steep gradients for short distances had been recently worked in this country successfully, both from a practical and financial point of view. Across a valley, where the gradients were 1 in 5, 1 in 7½, and 1 in 12½, stationary engines, with drums and wire ropes, had been employed to haul the traffic. On the rest of the railway, having gradients in some places of 1 in 9, 1 in 10, 1 in 14½, 1 in 17, &c., locomotives alone, without the aid of a central rail or racks, were used. The railway referred to was a temporary one, laid by the contractor, Mr. Joseph Firbank, of the Lewes and East Grinstead railway, on the surface of the ground, along the "cess," for the purpose of transporting plant and materials required in the construction of the permanent works. This line showed the feasibility of working excessively steep gradients for short distances, which might with advantage be adopted in countries where the surface of the ground was irregular, where there would not be a large amount of heavy traffic, and where the available funds would not admit of expensive works. The rails used were flat-bottomed, of various sections, mostly 56 lbs. per yard, laid on Scotch fir cross sleepers, 7 feet long by 7 inches wide and 3½ inches deep, to the ordinary 4 feet 8½ inches gauge, with little or no ballast. For one deep valley winding engines were used, and elsewhere tank locomotives. On the north incline of the valley was a portable 10-HP. engine, with double cylinders and overhead winding-drum, 5 feet in diameter; and on the south incline of the valley was one of 20-HP., but with a drum, 4 feet 8 inches in diameter, attached to the side, and on the ground. An iron-wire rope, 1 inch in diameter, weighing 4¾ lbs. per lineal yard, was used on both inclines; on the north it was 290 yards in length, and on the south 280 yards. A horse was necessary on each incline, for shunting purposes, and occasionally to draw the shackle and rope down the incline. A Mr. Robinson

Robinson. single line of rails was laid down each incline, and a double line in the bottom, with self-acting balanced points, to allow of the passage of wagons. The engine on the north incline was capable of drawing up a load of 12 tons; that on the south a load of 16 tons. Eighteen loaded wagons had been passed from one side to the other in two hours and three-quarters, but the usual number in a day of ten hours was fifty, representing a weight of 250 tons from north to south alone. With the appliances, 660 tons, exclusive of the weight of the wagons, could have been, if required, transported across the valley; that was 330 tons in each direction in a day of ten hours. The contractor's agent calculated the cost of hauling 1 ton across the valley, including wear and tear of engines and machinery, at $4\frac{3}{4}d.$ The tank locomotive had six wheels coupled, with 12-inch cylinders and 20 inches length of stroke, and weighed when in steam 16 tons. The wheels were 3 feet 1 inch in diameter, and had a total base of 10 feet 9 inches. This engine was capable of drawing two trucks of coal weighing 24 tons up the gradient of 1 in 9 by running down the gradient of 1 in $14\frac{1}{2}$, but only one truck, or 12 tons, starting from the bottom, and only one truck up the gradient of 1 in 15 at Sharp Thorn, where there was a curve of 250 feet radius over the tunnel entrance. The time occupied in running from the south incline to Sharp Thorn, a distance of nearly 4 miles, and back again, including shunting and changing wagons, was one hour. The engine alone performed the single journey in twelve minutes. The contractor's agent calculated the cost of hauling 1 ton of net load at a fraction over 1*d.* per mile. This engine was capable of transporting 150 tons in 1 day, exclusive of the weight of the wagons, over the 4 miles referred to in one direction. Heavy trains were hauled in detail up the steepest gradients where shunting sidings were provided. With reference to adhesion some experiments to determine the coefficient of friction of the various kinds of iron and steel used in the manufacture of driving wheels and rails, and with the locomotives and rails themselves would be useful. According to Rennie's experiments, the constant fraction which the friction was of the insistent pressure, was rather more for cast iron and wrought iron than for wrought iron and wrought iron. The coefficient for cast iron and wrought iron he gave as $\frac{1}{5 \cdot 87}$, corresponding to a limiting angle of resistance of 9° 40′, and of wrought iron and wrought iron as $\frac{1}{6 \cdot 26}$ corresponding to a limiting angle of resistance of 9° 5′, but these were under pressures of 36 lbs. per square inch only, and it was well known that friction under heavy pressures increased very con

ily. It might be found that American engine driving- Mr. Robinson.
, cast with chilled faces, had an advantage as regards
on over others of a different description. With respect to
y curves, although they were set out in the first instance as
is of a true circle, they were, when the rails came to be laid,
ed at the two ends, and in some measure approximated to
lic curves.

A. H. ROWAN observed that it had been stated by Mr. Mr. Rowan.
hers that Wellington was the only port in the whole island;
re, as the country was rapidly being developed, the amount
ic which would eventually have to be hauled up this incline
be enormous, and every available means of increasing the
on, whether by Fell engines or other similar arrangements,
be absolutely necessary. At present it appeared that about
assengers were carried up the incline for every 4 tons of
and it was probable that this ratio would be maintained.
the passenger traffic being to the goods traffic as, say, one to
, the adhesion required to haul the passenger traffic would
e one-twelfth of that required for the goods traffic, and
ore, if the passenger traffic were separated from the goods
, the Fell engine would be unnecessary for the passenger
. He therefore wished to direct attention to the principle of
cle specially adapted for passenger traffic on steep gradients.
vehicles might be called "combined cars," and there were
l daily at work in Germany, France, and Belgium. They
ot, however, hitherto been called upon to work on any
nt which approached in steepness to the New Zealand one,
principal recommendation having hitherto been their com-
es and economy. It had been abundantly proved that any
e had in its own weight sufficient adhesion to haul up an
e of 1 in 15, a load equal to the weight available for adhesion.
take a loaded combined car composed of

	Tons.
One four-coupled engine . . . weighing, say	10
„ four-wheeled hind-bogie . . . . „ „	1
„ car for sixty passengers . . . . „ „	9
An average load of forty-five passengers „ „	3
Total weight	23

car acted as a rigid connection or girder between the engine
ind-bogie, then the weight available for adhesion on the
g-wheels would be 16 tons. As the adhesion of a 16-ton
upled engine would take something more than a total

Mr. Rowan. weight of 32 tons up 1 in 15, *à fortiori* it would take 23 tons. In descending inclines a "combined car" had eight wheels to brake, with the whole weight of vehicle and load available for adhesion between the rails and the skidded wheels.

Mr. Smythe. Mr. A. J. HAMILTON SMYTHE observed, in regard to the New Zealand Government Railways, that in the comparative table of receipts and expenditure, during the periods of twelve months before and after the opening of the incline of 1 in 15, the receipts and expenditure per mile of line opened appeared to be considerably in excess of the quotients obtained by dividing the total sums received and expended by the numbers of miles of line open. This needed explanation. If the alternative extension, with gradients of 1 in 40, and 5 miles longer than the route adopted, had been constructed, the cost per mile of working the whole 50 miles would probably not have exceeded the cost per mile of working the first 28 miles, which included 7 miles with a gradient of 1 in 35. On this assumption the total cost of working the whole line would have been £20,925, showing a saving of £1,994 on the cost of working the line as constructed. Where competitive lines did not exist, the fares and freights were usually fixed at a price per mile measured along the railway. Hence, if the longer line had been constructed, the total receipts would probably have been to £30,400, as 50 was to 45, or would have amounted to £33,777, being a further gain to the alternative line of £3,377; and taking the £1,994 saving on the expenditure, there would have been a total of £5,371 a year to set against the £5,000 a year interest payable on the additional capital required for the construction of the longer line.

It could no doubt be urged in reply to this that increased charges, due to an additional length of line between the same two points, were not legitimate when considered for purposes of comparing the advantages to be conferred on a town or district by the adoption of one or other of alternative routes, especially when the cost of the line had to be borne by those using it. It might be remarked, however, that as the proportion of weight of engine to gross load carried would be smaller on the longer line with a gradient of 1 in 40 than on the shorter line with one of 1 in 15, the train-mile on the former would represent a greater paying tonnage conveyed than a train-mile on the latter. This advantage would probably much more than compensate for the longer time occupied on the journey, though its value could not be exactly determined unless ton-miles were substituted for train-miles in the table of results furnished in the Paper. The Author of the Paper

n the maximum gross load that an engine could take up Mr. Smythe.
ient of 1 in 15. If he would also give the maximum
d taken up the 7-mile gradient of 1 in 35 round 5-chain
, better estimate could be made of the cost of working the
ve extension, as it might be assumed that it would be
e same as working up the gradients of 1 in 40 round
curves. The difference between the amounts earned by
orking up gradients where, as stated in the Paper, an
ould only convey a maximum load of 63 tons, and the
earned by trains of 300 tons running on flat gradients,
reat that the adoption of a train-mile unit for purposes of
ıg the comparative economy of routes, involving gradients
iffer much in steepness, seemed practically useless; and
urns could be obtained showing the cost of conveying tons
and passengers over lines of known gradients and lengths,
stion of the relative economy of lines with different
s must remain obscure.

. E. SPOONER observed, by the description of the country, Mr. Spooner.
t part of the north island of New Zealand traversed by
way was of a rude character, necessitating the adoption of
rves as a means of reducing the cost of construction, and
rves of 5 chains radius pervaded the greater part of the
n a gauge of 3 feet 6 inches ordinary stock would, it was
ı upon such curves, but the strain on the axles and bear-
st be considerable, and hence undue friction and unneces-
sumption of fuel. As the rolling stock on the Wellington
herston line had not been described, he concluded that
the ordinary English construction was in use; but he
ɔt refrain from remarking that rolling stock of a special
r would be preferable for the line, such as the bogie
ɔr the Grover or Cleminson system of radial axles, though
ght that the bogie system was practically the most de-
ɔr safe and easy running, as also giving better capacity
ɔ.

the accounts of the various routes surveyed for the Wel-
line, it appeared that there was no alternative but to
ıd construct the one chosen with the incline of 1 in 15,
ə Fell system for working the traffic over it, the other
the line being worked with ordinary locomotives. In
tries where frequently almost insurmountable difficulties
; with, such as had been met with on the Wellington and
ton railway, it was questionable whether another plan of
ɡ steep gradients with greater utility and economy could

Mr. Spooner. not be brought into use. For the same reason of adopting s gradients for a short part of the line, leaving the rema portion with easy and good working gradients, more particu with a view to lessen heavy expenditure in constructive v as with this line, he considered that the power of the ord locomotive might be successfully used jointly for steep inc with a self-acting incline with drum and rope arrangement, double for up and down lines, with the drum at the head o same, having coil and uncoil steel wire ropes. As one trai its combined weight, with a locomotive at the head of the in was attached, the other train and its combined weight, w locomotive, was attached to the rope and coupling at the the ascending engine, using its tractive power up the grad and when necessary the descending locomotive using its tr power down the gradient; hence not only having complete c over the trains by use of steam with the locomotives when train might by its weight preponderate, but also making use gravity of one in aid of the other, and thus avoiding the mode of the Fell engine and its accompanying gearing. Of there would be the cost of the extra line of way, drum mach ropes and rollers.

In the application of this system it would be desirable th incline should be made in as straight a line as possible, choose ground for its construction to as near a catenary cu the ground would admit, so as to avoid numerous central f rollers, reducing the number of rollers to a minimum, besid means of saving wear and tear of the rope. In the ev such selection of site there would still be the necessity for n the line of incline in a straight direction as one most des at the same time it might be made an undulating incline, of various gradients. This mode of working would not re change or alteration in either the ordinary locomotive or th further than a stoppage for coupling the trains to the rc the foot and head of the incline, and starting on receivi proper signals.

It was to be concluded that the train was furnished wit tinuous and special brakes to use at any time, even up greatest emergency, such as the rope or its gearing giving As a means of reducing the cost in the construction of an a single line of rails, instead of a double line might be mad a half-way passage, which would require safety points, charge of a signalman, though the first was preferable [redacted]orking, and would save the cost of a signalman.

Mr. Spooner.

The traffic of railways with inclines of from 1 in 15 to 1 in 30 could be well worked on this principle. By such a mode the difference to be overcome was the difference of weight between the up and down train, for or against, plus the weight and friction of the rope over rollers. If the down load of train was much in excess of the up load of train, the brakes could be used to regulate the speed; if less, then steam could be put on the locomotive till the proper speed was attained. The speed should be slow, and limited probably to 10 or 12 miles an hour, not but that greater speed might be applied if necessary. There would also have to be a limit to the weight of the train, so as not to place too great a strain on the rope; probably a maximum of gross weight of 120 tons; but such would be regulated by the gradients adopted for the incline. There would be the question whether the system here propounded could be made applicable, say upon an incline as now worked by the Fell engine at Mungaroa, where the curves were sharp and numerous. Such would be somewhat intricate and would involve the necessity of combined central and vertical rollers between the rails, besides a special arrangement for central rope couplings, which, by suitable mechanism, might, he believed, be effectively and practically carried out.

Another mode of working traffic over steep gradients would be by laying ropes of steel or other suitable material along the line, and fixing the ends at the top and bottom of the incline to a screw anchor coupling, drum or other fastening. Holders would be fixed on the line for carrying and guiding the ropes where necessary. On the locomotive engine, pulleys would be fastened on the driving axles, or on axles fixed at the leading or trailing end of the locomotive, and connected with the axles of the driving-wheels by cranks or gearing. When an engine and train arrived at the foot of the inclined plane the ropes would be uncoupled from the fastenings and passed round the pulleys on the locomotive engine, and the end of the ropes made fast to the screw anchor coupling or drum, and tightened up, the other end of the ropes being fast at the top of the incline. The locomotive with the train would then proceed up the gradient, and be able to apply its full tractive power through the adhesion of the ropes on the pulleys. When the train reached the top of the incline the ropes would be uncoupled from the fastening, taken off the pulleys on the locomotive, and recoupled to the anchor fastening. When a train was descending a steep gradient the ropes could be used as a brake power with the

r. Spooner. locomotive engine. Passenger trains would be supplied with continuous and automatic brakes, and also with a special arrangement of brakes for stopping trains in case of accident. The operation might also be carried out with a single rope and pulley.

He had made an experiment with a small four-wheel model engine, complete in all its parts, called "Topsy," constructed by Messrs. G. P. Spooner and W. Williams, with cylinders $1\frac{3}{8}$ inch in diameter, stroke $1\frac{1}{16}$ inch, and with wheels $3\frac{2}{16}$ inches diameter on the tread; its weight in working order was 60 lbs., and it had been tested to a pressure of 110 lbs. The experiment was made, on a line of $3\frac{1}{8}$ inches gauge, to show the comparison of working the engine without and also with the system of the ropes and pulleys as above described. This system was an invention of Mr. J. Sylvester Hughes of the Festiniog railway.

Experiment No. 1.—On the level the engine was weighted with a saddle load of 16 lbs., making a total weight of 76 lbs. At a steam pressure of 80 lbs. per square inch it took a gross load of 989 lbs. exclusive of the weight of the engine.

Experiment No. 2.—On a gradient of 1 in 15, with the engine weighted as before, and a mean pressure of 75 lbs. of steam per square inch, it took a gross load, exclusive of the engine, of 203 lbs.

Experiment No. 3.—On a gradient of 1 in 15, with two ropes passed over the two adhesion pulleys on the engine, and the ends fastened at the top and bottom of the incline, the pulleys being fixed on an axle at the trailing end of the engine and driven from the driving-wheels by a crank; at a mean pressure of 75 lbs. of steam per square inch, the gross load carried, exclusive of the weight of the engine, was 549 lbs., the tension weight on each rope being 14 lbs.

Experiment No. 4.—On an incline of 1 in 6, with the engine saddle weighted as before with 16 lbs., working without ropes, at a mean pressure of 75 lbs. of steam per square inch, the gross load carried, exclusive of the weight of the engine, was 49 lbs.

Experiment No. 5.—On an incline of 1 in 6, with ropes as in experiment No. 3, and the mean pressure of steam per square inch 75 lbs., the gross load conveyed, exclusive of the weight of the engine, was 155 lbs., the tension weight on each rope being 28 lbs.

r. Watson. Mr. J. W. MITTON WATSON had been engaged on the construction of a portion of the incline on the first Ceylon Government railway, gradient 1 in 45, with 10-chain curves. He had charge of the construction of an incline of 1 in 13 on a branch of the Taff Vale

railway, and had also been employed as district engineer on the Great Indian Peninsula railway, on which were the celebrated Thull and Bhore Ghâts; but all these sank into insignificance when compared with the Oroya railway in Peru. He had frequently travelled over it, and in connection with it he had been presented with a commemorative bronze medal. The line left Callao at the level of the wharves, and reached a height of about 15,000 feet above the sea, having a ruling gradient of 1 in 25, and curves of 120 feet radius. There were numerous reversing stations, nearly sixty tunnels, and an iron viaduct 240 feet high. This viaduct was on the American truss system, but as the piers were composed of very thin wrought-iron columns, arranged somewhat after the plan of the cast-iron ones in the Crumlin viaduct, he anticipated that rust from the inside of the columns would make their durability very questionable. The line was worked by American locomotives, eight wheels coupled, with a four-wheel bogie in front, and, with the exception of those in the bogie, the trailing wheels alone of the engine had flanges. They appeared to work well, but with even the best American spark catchers the ground near the line was blackened with small coal and ashes. He had known, in several instances, where American engines had been worked in conjunction with English ones, the latter had a marked superiority on the score of durability. During the time he was on the Taff Vale railway, a gradient of 1 in 17 on the main line was for some time worked successfully by ordinary locomotives. Mr. Watson.

Mr. J. C. WILSON considered the Fell central rail system of railway to be the best, safest, and most economical system yet devised for ascending and descending very steep inclines, for the following reasons:—1st. It possessed the great merit of simplicity. The special tractive power for the inclined part of the railway was of the same character as for the ordinary part, the only difference being in the form of its application. The ordinary locomotive engine was employed on the more level portions of the railway until the incline was reached, when the central rail engine, which was built inside of the ordinary engine, grasped the Fell central rail and thus easily acquired the additional tractive power to enable it to ascend the incline with its load. 2nd. It had the capacity of admitting of almost any increase of power to meet the requirements of almost any incline or of any load, the adhesion of the driving-wheels to the central rail being obtained by means of springs instead of by the mere weight of the engine, and by such means of course almost any amount of adhesion could Mr. Wilson.

Mr. Wilson.

be obtained. 3rd. In reference to the descent of the incline (a matter of equal if not of greater importance than its ascent, especially with regard to safety), the Fell central rail afforded the opportunity of a clip brake being applied to it (not to the driving-wheels), which was capable of immediately arresting the progress of any train, for it simply held fast by the whole length of the central rail; and the said rail was also a most efficient guide to the engine, tending to keep it on the rails, in fact it almost entirely prevented the possibility of its leaving them. 4th. The strength of the couplings throughout the train being necessarily very great in order to drag the required load safely up the incline, and the engine being, as above remarked, prevented leaving the rails, it followed that, in the event of a carriage or wagon getting off the rails behind the engine, there would always be a reasonable probability of its being dragged on to them again; or, at all events, no very serious accident could ensue. 5th. The ordinary carriages and wagons could be freely used for this system by merely adding to the strength of the draw gear. As to the points referred to in reasons 3rd and 4th, bearing, as they did, very strongly upon the question of public safety, he would refer to the account of the recent accident on the Wairurapa side of the Rimutaka hill in New Zealand, where the Fell central rail line was in use. It was therein distinctly stated by one of the survivors that if it had not been for the engine holding on to the rails as it did do, and to the strength of the couplings, a most fearful catastrophe would have ensued. It seemed to be noteworthy, in connection with that accident, that the carriages were being pushed up, instead of being dragged up the incline as usual.

As the manager of the Avonside Engine Company, he had undertaken to design and manufacture these four engines for Messrs. Hemans and Bruce. The usual drawings could not be supplied. Fell central-rail engines, it was known, had been manufactured before, chiefly on the continent, but they had all been more or less failures. A few odd tracings of parts of those engines were seen, but they were put entirely aside; and these four engines were designed *de novo*. And here he might mention, as a matter of history, that the largest share of the credit for the invention and design of these engines was due to a Swedish gentleman, Mr. H. W. Widmark, an engineer of acknowledged great ability in the construction of locomotive engines. The engines were duly manufactured, and one of them was tried on the 12th of February, 1876, upon a piece of railway of 3 feet 6 inches gauge, laid down for the purpose at Bristol. The trials were eminently satisfactory;

only one tooth of the spur wheels of the internal engine gave way. Mr. W
These wheels were made of cast steel; afterwards a spare set was made of the very best quality of forged crucible steel, slotting out the teeth. At the time the tooth in question gave way, the inside engine was being driven in opposition to the outside engine under the condition of having just sufficient pressure on its springs to render its adhesion equal to that of the outside engine; the wheels were sticking for the moment; the driver kept turning on the steam, when the wheels slipped and the engine ran away. Although the trial at Bristol was necessarily a limited one, it was a very severe one in regard to testing the strength and general working of the engines. It was satisfactory to note that only the trifling defect of the failure of one small bolt was found in those engines. This bolt was considered to be only a safeguard, the pressure on the top bearings of the vertical shafts resulting from the springs below amounting to upwards of 4 tons; but as a safeguard it seemed that the bolt in question ought to have been made stronger. In the construction of these engines, there were points of novelty in, (1) the framing, especially of the inside engines; (2) in the valve gear of the inside engines, which had no eccentrics; (3) in the mode of coupling the four vertical shafts of the inside engines together; (4) in the regulator apparatus, there being a separate regulator and handle for each engine, but with the handles so arranged as to be capable of being combined, and thus to allow of the admission of the steam to each engine separately or unitedly, as might be required. It was necessary at first in starting with a load to regulate each engine separately until they each came to perform their proper share of duty; afterwards the two handles could be locked together, and the admission of the steam for both engines regulated by one handle in the usual way. Furthermore, in order to avoid a waste of power through friction in passing round the sharp curves of the line these engines had their trailing axles fitted with Widmark's radial axle-boxes, an invention which, from its simplicity and neatness as well as from its efficiency and cheapness was found to be admirably adapted for the purpose. A bogie was found to be too cumbersome for such engines, especially for 3 feet 6 inches gauge, and it was found to have besides the serious disadvantage of prolonging the tail of the engines too far, with a consequent very prejudicial effect upon the draw gear. Such engines were required, in fact, to be made as short and compact as possible, especially when two were to be worked coupled together, as was stipulated in this instance. Finally, new combined central buffing and draw gear apparatus

ilson. was specially designed for these engines. He had purposely dw upon the construction of these engines because they were tru marvellous, and the success of this Fell central railway system truth mainly depended upon them. These engines were entire novel; and they were the first really successful engines of t kind.

In one of the trials at Bristol, the inside engine was set forward and the outside in backward gear, and full steam w turned on to both of the engines, the result being that the insi or Fell central-rail engine skidded the wheels of the outside engi and dragged them along. The special piece of line on which t trials were made was laid with a sharp reverse curve, in or to completely test the central-rail system in combination wi the outside engine with its radial axle-boxes on such a cur Both acted perfectly. The Avonside Engine Company had und taken to fulfil the following requirements, viz., that two of t engines coupled together should be able to draw 100 tons, exclus of their own weight, up an incline of 1 in 15, the working press of the steam being the same as in the other New Zealand engir viz., 130 lbs. per square inch.

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30 November, 1880.

JAMES BRUNLEES. F.R.S.E., Vice-President, in the Chair.

The discussion upon the two Papers, "New Zealand Gov ment Railways" and "Ceylon Government Railways," occu the whole evening.

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7 December, 1880.

WILLIAM HENRY BARLOW, F.R.S., President, in the Chair.

The following Associate Member has been transferred by the Council to the class of

Members.

HENRY TOMLISON.

The following candidates have been admitted by the Council as

Students.

CHARLES ARTHUR ALBERT BARNES.
WILLIAM HENRY BIRD.
HARRY FREESTONE BULL.
FRANK PLANT COOK.
ROBERT DOUGLASS.
WALTER MORRIS EYRE.
SACKVILLE FISHER.
LEONARD GILL.
FRANCIS THOMAS HAMMETT.
JOHN HAMPTON HEARSEY.
ALBERT JAMES KNOWLES.
PHILIP VINCENT LANDER.
HERBERT HENRY LAW.
ALBERT WILLIAM DONNE LEWIS.
GRIFFITH LLOYD-JONES.
ARTHUR MONCKTON.
WILLIAM OXTOBY.
JOHN FALKNER PADDON.
EDMUND HOLME PATTINSON.
WILLIAM PERCY PRENTICE.
DASHWOOD POYNTZ RICKETTS.
ROBERT ROBERTSON.
WILLIAM HAYWARD RUSHTON.
FREDRIC JOSEPH SCOTT.
AUGUSTUS JOHN SIMPSON.
THOMAS STEWART.
WILLIAM LUMISDEN STRANGE.
ALEXANDER PELHAM TROTTER.
HENRY TYNDALL WAKEFIELD.

The following candidates were balloted for and duly elected as

Members.

STANLEY DE VERE HASTINGS ALEXANDER.
LOUIS FREDERIC GUSTAVE BOUSCAREN.
WILLIAM WOOD CULCHETH.
WILLIAM JOSEPH FAHIE.
GEORGE FOOT.
HOLT SAMUEL HALLETT.
ARTHUR LUKE.
ANTONIO GOMES DE MATTOS.
WILMOT JAMES ROSE.
NORMAN SELFE.
DAVID LEES SIMPSON.
FRANCIS JOHN WEIGHELL.

Associate Members.

Percy Leonard Addison, Stud. Inst. C.E.
Robert Philip Atkinson, Stud. Inst. C.E.
Thomas James Bailey.
Edward Skelton Bellasis, Stud. Inst. C.E.
William Benjamin George Bennett.
Edward Peto Betts, M.A.
John Boylan.
Joseph John Browne.
Charles Campbell.
James Husband Carvosso.
John Edward Catton, Stud. Inst. C.E.
William Collingwood.
John Henry Cox.
Samuel Fitzhugh Cox.
Jamsetjee Nesserwanjee Dady.
James Eldridge, Jun.
Robert Ellis.
William Ferguson.
Sidney Birdwood Fox.
Sidney Gompertz Gamble.
George Gooch, Stud. Inst. C.E.
John Edward Hargrove.
Robert Harvey.
John Baillie Henderson.
Thomas Edward Ivens.
Edward Wilthew Jackson.
Neil Kennedy.
John Charles Lang, Stud. Inst. C.E.
Octavius Langtree.
James Ormsby Lawder.
Charles Coxhead Lindsay.
James Edward Lingard.
Henry Luckstedt.
Henry Lyon.
Thomas Melbourne MacFarl[redacted]
Alexander Maclachlan, Stud[redacted] C.E.
George Valentine Martyn.
Edward James Moore.
George Edward Moore.
George Moyle.
Robert Charles Frederick Og[redacted]vie, Stud. Inst. C.E.
Charles Reginald Parkes, [redacted]tud. Inst. C.E.
Septimus Penny, Stud. Inst. C.E.
Henry Handley Pridham Pow[redacted]
Edward Robins, Stud. Inst. C.E.
Hugh Cecil Robinson, Stud. [redacted]nst. C.E.
Mackay John Scobie, Stud. Inst. C.E.
Henry Augustus Severn.
Luke George Sgouta, Stud. Inst. C.E.
Henry Selby Hele Shaw, [redacted]tud. Inst. C.E.
Arthur Stannard.
John Stansfield-Broun.
Robert Henry Frederick St[redacted]rt, Stud. Inst. C.E.
John Henry Taylor.
Henry George Thompson.
William Thomson.
Benjamin Howarth Thwaite, [redacted]tud. Inst. C.E.
Joseph Tyson, Stud. Inst. C.E.
John Henry Wallace, Stud. [redacted]nst. C.E.
Henry Edward Worsley.
Barclay Hughes Young, Stud. [redacted]nst. C.E.

Associate.

George Matthey, F.R.S.

(*Paper No. 1732.*)

"The different modes of Erecting Iron Bridges."

By THEOPHILUS SEYRIG, M. Inst. C.E.

Translated by ALFRED BACHE, B.A., Assoc. Inst. C.E.

IN the records of engineering works—harbours, canals, bridges, or roads—the science brought to bear in their execution seems most generally to be measured by the result achieved. There are however two other aspects in which such works may be studied, and in which they afford equal proof of the ability of their designers: these are, firstly, their net cost; and secondly, the methods employed in their execution. The best possible work, carried out with the fewest resources and at the least expense, is the problem to be solved by every engineer. While such works as the pyramids of Egypt or the network of Roman roads fascinate by their vastness, the interest they awaken would be largely enhanced, were there reason to think they had been carried out by other means than mere brute force of numbers. Far more genuine satisfaction is derived from tracing the gradual progress of improvements in the means employed for the construction of useful public works with less expenditure both of time and money.

The slowness of this progress in preceding centuries has been notably redeemed in the present, conspicuous not only for the extent of work done, but for the rapidity with which it has been performed. It is to be hoped the latter feature will not hereafter be found to have entailed too great a sacrifice of quality, substantial character, and tasteful design; and that the processes invented in this age of progress will also leave behind them evidence, not of lavish expenditure, but of prudent economy.

In the construction of Bridges generally, and of iron bridges more particularly, a great advance has been witnessed. Until the end of last century the only material used for bridge building was stone or wood. The two exceptional instances at Coalbrookdale and Buildwas, though not constituting a new class of structure, mark the commencement of the new era, in which so important a part was to be played by iron—whether as wrought iron, cast iron, wire, or steel. The introduction of this new material into the arts of construction led also to the invention of new modes of procedure, applicable to the new forms of structure, as well as to the ever increasing difficulties to be encountered.

In the present short sketch of the methods adopted and the i provements effected, the Author is desirous of drawing attent to the principles that should be followed in the Erection of I Bridges. His remarks will be confined to works of this class, the first place because so little progress has been made in the c struction of stone or timber bridges, and next because of t prominent position now occupied by large iron structures.

The various modes of erecting iron bridges may be classed as

I. Erection upon Staging.
II. Erection by Floating of girders.
III. Erection by Protrusion, or pushing and rolling over of girde
IV. Erection by Overhang, or building out.

I.—Erection upon Staging.

The earliest iron bridges were merely copied from those p viously constructed of stone, the arches at Coalbrookdale, Buildw and Wearmouth, being built up of cast-iron voussoirs. Their e tion would naturally be accomplished in the same way, by usual elaborate staging: which has invariably been adopted in cast-iron bridges hitherto constructed, since these are never c posed of straight girders, but always of arched segments, butt against one another with plain ends, and ill adapted for allow any deflection at the joints.

For the erection of wrought-iron bridges also, though these mostly constructed of straight girders, staging has neverthe been frequently used. Up till 1850 that was the sole mod erection employed, in spite of its great cost; and it remained the combined skill of a knot of rarely gifted engineers to prove, the memorable success of the Britannia bridge, that the erec could be achieved in a better, safer, and cheaper way by abandon the use of auxiliary framework.

Two different kinds of staging are employed, according to section of the river or valley to be crossed:—(*a*) piles or stands spaced in rows at equal distances apart; (*b*) piles or stands clustered together, leaving wider spaces between the clusters.

(*a*) *Standards equally spaced.*—The inconvenience of this arran ment is its impeding the water-way considerably. It is theref unsuitable for navigable rivers, or for those liable to floods o the drifting of ice or other floating substances. In general it requi a larger quantity of timbering and a greater number of standa than the clustered arrangement. It is largely employed in

United States, having the advantages of easy erection, and of being made up of similar pieces repeated a great many times over. Where there are special reasons for adopting it, while at the same time the water-way is required not to be impeded, a frequent expedient is to construct one span at a time, so as to obstruct the stream as little as possible.

Allgyö Bridge.—Staging with equal spacing was employed for the large railway bridge over the river Theiss at Allgyö in Hungary, which is illustrated in Plate 8, Fig. 1. The long span of 328 feet was subdivided into ten bays of 30 to 40 feet, leaving a central opening of 65 feet for the passage of boats, which was spanned by Howe lattice trusses.[1] The river being here very deep, piles as long as 65 feet had to be used. The underside of the permanent girders is about 89 feet above the river bed; and the depth of the girders being 34¼ feet, the total height of the staging is more than 125 feet. For a timber structure this is a remarkably bold one, considering that the bridge is for a single line; the width between the girders being only 16½ feet is very narrow in proportion to the height; and for a great part of its height the staging is exposed to the side pressure of a strong current.

Erdre Bridge.—A similar arrangement of staging has recently been adopted for the railway bridge over the river Erdre at Nantes in Brittany,[2] which has a single arch of 321-feet span, carrying a double line of rails, and is constructed entirely of plate-iron. The river being a small one with but little navigation, the rows of standards spaced 26 feet apart presented no inconvenience; a central opening of 40-feet width sufficed for the passage of boats. The extreme height from the ground to the crown of the arch being only 56 feet, this construction of staging was perfectly satisfactory.

Znaim Viaduct.—Viaducts crossing valleys at a great height are seldom erected on staging. A curious instance of the use of staging in such a case is afforded by the railway viaduct over the river Thaya at Znaïm in Moravia, illustrated in Plate 8, Fig. 2. It is 722 feet long, and its height varies from 118 to 138 feet above the ground, the rail level being 157 feet above the water. Notwithstanding that the superstructure was composed of continuous girders, a complete staging was here erected. The timbers employed were generally neither squared nor framed into one another,

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., pp. 306–8.
[2] *Ibid.*, vol. lx., p. 426.

but were put together with cramp irons, with but few incli braces. The standards were spaced 43 feet apart, with int mediate uprights which carried no weight but served only stiffening struts; ledgers or horizontal ties were fixed in ti 30 feet one above another. This staging cost about £2,000, about £3 12*s.* per ton for the 560 tons of iron in the viaduct, wh is a comparatively low rate for so considerable a height of structu

(*b*) *Clustered Standards.*—In the second kind of staging, hav the standards clustered together, with wider spaces between clusters so as to impede navigation as little as possible, the op ings have to be spanned by special trusses or by centering. For erection of bridges above 60 or 70 feet high this is in general excellent arrangement; the Allgyö and Znaïm bridges alre noticed are exceptions. As the piers and abutments of the bri often require similar scaffolding for their erection, this come then all the more advantageously for the subsequent erection of superstructure. Except where the ground is hard enough for timber uprights to bear upon it direct, this class of staging, the preceding, requires driven piles to carry the standards. I cluster of standards is united to the next by simple trussed be or Howe trellis trusses, or very light wrought-iron girders; g rally however the most satisfactory mode is a system of timber struts.

Pont du Carrousel.—One of the earliest bridges erected in way was the Pont du Carrousel, Paris, built in 1834–36 with iron arches; it has served as a pattern for several other struct of the same kind, and in simplicity of timbering has hitherto unsurpassed. It has three openings of 157 feet width, eac which was subdivided into three bays of 44, 69, and 44 feet w by two rows of close standards carrying the temporary floorin the erection of the arches. Each row was 43 feet long, and tained thirty-six timbers, twenty-four of them upright, and tv inclined so as to prevent all possible racking. There were decks or courses of flooring, following as closely as possible lines of the intrados and extrados; wood chocks were the that was required for adjusting the cast-iron arches in posi The economical and simple manner in which the timbering here employed is worthy of notice; and it is seen at a glance it would be difficult to put up a simpler or cheaper staging.

Bordeaux Bridge.—Many other bridges might be menti which have been erected in the same sort of way. In that at [redacted] for instance, though the girders were continuous fo

whole length of the bridge, they were erected on staging, instead of being protruded or pushed across the openings; the clusters of standards were about 65 feet apart, from centre to centre. The current of the Garonne, aided by the tide, being much more powerful than that of the Seine, necessitated very strong piers for the staging; and each cluster of standards was accordingly made up of five rows, with eighteen to twenty piles in each row. The bridge spans of 253 feet were thus subdivided each into four openings of only about 49-feet clear, which were crossed by inclined struts. The platform was in two tiers, for the upper and lower members of the girders. The cost of this staging, in which timber had not been spared, amounted to about £3 4*s.* per ton of superstructure erected.

Kuilenburg Bridge.—The largest bridge in existence with horizontal girders was also erected on a staging of this kind: namely the railway bridge over the Lek at Kuilenburg (or Culenborg) in Holland,[1] which has a span of 492 feet clear opening, as shown in Plate 8, Figs. 3 and 4. The platform of the staging for its erection was 39 feet above low water, and 52½ feet above the bottom of the river; it was carried on five clusters of piles, averaging 82 feet apart from centre to centre. The clusters were connected by inclined struts, which helped to support the platform. Upon the platform were erected a series of uprights, the tallest of them 65 feet high, which were connected longitudinally by three tiers of ledgers, with transverse braces and counterbraces. This timbering served to support during erection the lattice sides o the girders, as well as their top members. Altogether the whole staging contained over 81,000 cubic feet of timber and 5 tons of bolts. The weight of the bridge superstructure being 2,150 tons, there were thus 37¾ cubic feet of timber per ton of superstructure erected, which quantity represents an extremely high cost for the staging, whatever be the price of the timber. This staging moreover narrowly escaped an accident which would have involved the failure of the whole work. During the erection, a settlement of about 7 inches took place in the piles, which had to be counteracted by numerous re-adjustments in erecting the girders. And just when the work was nearly completed, one of the timber piers was undermined by the water, and threatened to bring down the entire staging; the disaster was with difficulty averted by great exertions.

Other Dutch bridges of nearly the same pattern have been erected on the same principle.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. liv., pp. 187 and 237.

Bommel Bridge.—This railway bridge[1] crossing the river Waal had exactly similar staging. Its spans of 393 feet were divided into five openings by four clusters, each containing twenty-four piles, except those next the bridge piers. The water-ways left clear for the navigation were from 92 to 98 feet wide. The uprights of the staging built on the piles were united by horizontal timbers in four tiers, on each of which a working platform could be laid. Each span of the bridge weighed 800 tons; and its staging contained 51,200 cubic feet of timber, or 64 cubic feet per ton of superstructure erected, which exceeds the timbering for Kuilenburg bridge. At Bommel bridge however the same timber was used that had done duty before; and the net cost of erecting the bridge proper, owing to the work being so easy, was reduced as low as 15*s.* per ton. The erecting was also done very quickly, the last span being completed by ninety men in forty days.

The staging, having to serve as a temporary working platform is almost always constructed of timber. In a few instances however, where it has seemed necessary to have recourse to a stronger and better material, iron has naturally been selected for the purpose; and an iron framework has first been constructed, as light as possible, on which to erect the much heavier permanent bridge framing. Two examples will suffice to illustrate this mode of procedure, and to show the reason for its adoption.

El Kantara Bridge.—Built in 1866 across a deep gorge in Algeria with precipitous sides nearly perpendicular, and exposed to violent gusts of wind, this bridge has a clear span of 184 feet, and is at a height of 393 feet. A staging of that height being out of the question, the plan was adopted which had been formerly proposed by Robert Stephenson for the Britannia bridge, but afterwards abandoned. Across the gorge were first thrown a series of iron chains, securely anchored to masses of masonry on the viaducts forming the approaches to the bridge. From these chains was suspended by iron rods a light platform, on which were framed very light arches, with their upper surface shaped to the intrados of the bridge; they thus served both as centering, upon which it was then easy to erect the bridge superstructure, and also as stiffeners to prevent the chains from altering their curvature under unequal loading. This make-shift plan however has not been repeated elsewhere, the flexibility of the chains being always inconvenient for dealing with heavy masses, as in bridge erecting.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. liv., p. 246.

Kœnigswart Bridge.—A much better plan was adopted at Kœnigswart railway bridge in Bavaria,[1] crossing the valley of the Inn with the rail level 160 feet above low water, as shown in Plate 8, Figs. 5 and 6. It has three main spans of 227 feet from centre to centre of the piers, with a smaller opening beyond at each end. The girders being discontinuous could not be constructed on the bank and then pushed across to the piers. A main staging was therefore put up, supported at only a few points on clusters of piles. The piers being of masonry, the scaffoldings surrounding them were first put up, and were carried up to the top of the masonry and strengthened for supporting the superstructure. Midway between the piers a fresh cluster of piles was erected to within about 12 feet of the underside of the bridge girders. Each span was thus supported at three places, with 81-feet openings left clear between, which were crossed by very light wrought-iron lattice girders, 10 feet deep and 13 feet apart, all in single thicknesses. Cross timbers laid on these light frames formed the floor for erecting the permanent bridge framing with the greatest ease.

As soon as the two side openings were getting towards completion, preparations were made in the middle span for putting up the temporary iron staging. The twenty piles forming the middle cluster had been driven in March 1875, and fenced with an independent cutwater to protect them from floating bodies; and on them had been erected the uprights with their bracing. Floods in June however brought down quantities of brushwood, which caught at the bridge, and backed up the water to such a height as to sweep away first the cutwater and afterwards the timber pier itself. As the floods usually last all summer, and the work could not wait for new piles to be driven, it was determined to have recourse to a temporary wrought-iron framework stretching across the entire opening of the middle span.

By the time this temporary framework was ready, the two permanent side spans of the bridge had been erected. These were now used as fixed anchorages for the new temporary girders. At the head of the pier on each side of the middle span was fixed a trestle 16 feet high, stayed by flat tie-bars to junctions 33 feet behind in the permanent girders of the side spans. To the triangular truss thus formed were then braced in succession the overhanging portions of the temporary girder as these were severally got into place. The temporary girder, was of inverted bowstring form, the lattice consisting of simple triangles. The first panel, nearly horizontal, having been easily fixed overhanging from the pier, its

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lv., p. 347.

outer end was braced by an inclined tie-bar to the trestle on the pier head. The three next panels were then erected, and their outer end braced back by a second inclined tie-bar, by which the first was then superseded. After this the erection of the further panels was carried forwards, until the two halves of the girder met in the middle of the span. For providing against any inequality or error of measurement in the distance between the abutments, the anchorages were furnished with adjusting screws and universal joints, allowing range enough for bringing the two meeting ends together.

For facilitating the erection of these temporary girders, small swing cranes were placed on the outer end of the portion already erected, by which the separate pieces of the work were lowered and adjusted in position; as the erection advanced, these cranes were moved forwards continuously to the extremity of the erected portion. In order not to throw any more strain than necessary upon the anchorages, which had to sustain the whole load, only one-half or one-third of the parts composing the central portion of the temporary girders was erected in the first instance; as soon as the junction of the two meeting ends had been effected, the remaining pieces were added, and also the timber to form a flooring. The tie-bars were then removed, and the temporary girders and platform were lowered bodily about 6 feet, to a height suitable for erecting the permanent bridge girders in their places.

In determining the sections of these temporary girders, it was considered that much higher coefficients of working strain might fairly be allowed than for the permanent bridge. During the erection of the overhanging work indeed, the strain was not permitted to exceed 7·62 tons per square inch of section in any part. But a strain of 10·16 tons per square inch was allowed during the subsequent erection of the permanent bridge. The whole weight of this temporary framework was 84 tons; it had a clear opening of 215 feet, and was calculated for a load of 2 tons per lineal foot.

The whole of this work was done pretty quickly. The anchorages were fixed on the 23rd of September 1875; the junction of the two meeting ends was made on the 10th of November; the lowering of the temporary girders into position took place from the 17th to the 19th of November; and the erection of the permanent bridge girders was begun on the 8th of December, and completed by the 6th of January 1876.

Of the special features that characterise erection upon staging the first to be noticed is that it implies the use of a temporary [illegible]ture, which is in itself generally of high relative importance

ison with the permanent work. This means the sinking iderable sum, which it should be the aim to expend in ofitable or more useful way. Where wood is cheap how- cost of staging is not always so great as might be sup- rticularly where at the same time clever carpenters can be abour is inexpensive. Rapidity, convenience, safety, and of erection may then in many cases compensate for the e staging. This is still more true, wherever the same n be used over again for a number of similar spans, or for ructures of the same kind.

al disadvantage attending this class of work is the danger e whole of it may run, whenever a river is liable to drift. Mention has already been made of the haste with ilenburg bridge had to be completed, owing to one of the of piles having been undermined and the whole staging ettled down considerably. But more serious disasters the works of Hamm railway bridge near Düsseldorf in Prussia, crossing the Rhine with four spans of 340-feet ning each.[1] Three of these had been erected, and about he fourth, when on the 20th of November 1869 a heavily sel ran against one of the timber piers supporting the and brought it down, together with the whole of that the bridge; many of the workmen lost their lives. on being too far advanced to admit of reconstructing the that year, work could not be resumed till the following d it was the end of June 1870 before the bridge could be for traffic. The mishap at Königswart bridge, and the dealing with it, have already been described above.

reat advantage to be noticed in this mode of erection is y and facility with which the work can be carried on when staging has been completed for receiving the ironwork of anent bridge. The superintendence of the work is then riveting can be watched and examined at any time, and are less exposed to accident than in other modes of pro- Staging also allows the utmost freedom of choice as to the bridge to be erected, inasmuch as it facilitates equally the of arched ribs, bowstring girders, or bridges with continuous tinuous girders.

er consequence of erecting upon staging is that, prior to l completion, the bridge itself is subjected to no excessive uch as might entail the risk of its several parts not all

[1] *Vide* "Zeitschrift für Bauwesen," 1872, col. 369, and pl. 28.

taking their proper share of the work in the finished struct will be seen further on, that this condition is scarcely ever in the other modes of erection; and that these require arrangements and great precautions, for preventing the s of the different parts from being impaired. With staging no risk of the kind; every part of the bridge is dealt with se up to the time of the whole being completed, when each work thrown upon it for which it has been calculated a portioned.

Where time is of great importance, the working platform prepared while the ironwork of the bridge is also be ready, and the latter can then be erected without loss Some remarkable results have been achieved in this w most striking perhaps being furnished by the American of bridges, in which riveting is almost entirely banished f erecting platform, and the work is put together by means or bolts. As examples of what can be done in rapidity of in such cases, may be mentioned a railway bridge over the sippi, of 2,043 feet total length, including a swing openin feet; with its masonry piers and abutments the whole v structed in one hundred and fifty days from the date of t being given. Another railway bridge for a double line, of span, was entirely constructed in seventeen days, the having occupied only twenty-two hours. The railway bri the river Saco in Maine, 600 feet long, in five spans of 10(feet opening, having been burnt down, orders for its recons were telegraphed to Messrs. Clarke, Reeves and Co.; and bridge, entirely of wrought iron, was in its place forty da wards.

II.—Erection by Floating of Girders.

Stone being destitute of elasticity and possessing lov strength, arches built up of stone voussoirs have no sta stiffness until the keystone is in its place; previous to w entire structure requires extraneous support, and no overl be allowed in any portion. But with wood and iron the si ditions no longer prevail; and hence the adoption of the latt rial for bridge building led very speedily to new modes of among which the floating of the bridge girders ranks ea date. An iron girder, when completely put together, can b and handled as a single piece, care being taken to choose places by which to lift it. This consideration at once [illegible]cting the entire girder on land, out of reach of dan

floods and drift; and then conveying it bodily by sufficiently powerful appliances into the position it is to occupy permanently in the bridge.

Britannia Bridge.—Such was the view taken by the eminent engineers concerned in the building of the Britannia bridge, one of the earliest wrought-iron bridges, and to the present day one of the most remarkable. This work, due to the genius of Stephenson and Clark, has been so often described that no more than a cursory reference is here needed to the mode in which its erection was carried out with such signal success. The four tubes, each 470 feet long and weighing about 1,587 tons, had to be fixed at a height of 100 feet above the water, in a situation exposed to violent gales; and the work had all to be done without interfering with the navigation through the Menai Straits. Stephenson thought first of erecting the tubes in position by means of a platform suspended from cables thrown across from pier to pier, as was afterwards done at El Kantara bridge already mentioned. But the length of the span, and the danger which there was good reason to apprehend from the oscillations certain to be produced by the wind, led him to determine upon the bold and happy expedient that has since been so often repeated.

The tubes were constructed simultaneously on shore, upon a platform 2,200 feet long, built upon piles spaced 27 feet apart, the whole containing 110,100 cubic feet of timber. As soon as the first tube was ready, six pontoons were brought in underneath it between the piles, each pontoon being 98 feet long, 25 feet broad, and 8 feet deep. The rising tide brought these to bear up against the bottom of the tube, and lifted it off the platform; and by means of capstans on shore the whole floating mass was warped so as to bring the tube to the base of the bridge piers, and into the vertical plane in which it was to be fixed at the height of 100 feet. By then letting water into the pontoons, they were lowered and withdrawn from under the tube, leaving it resting on the masonry, each end fitting within a vertical groove left in the face of the pier; and the gradual lifting of the tube was continuously followed up closely by the building up of the grooves underneath it with masonry.

The lifting was done by powerful hydraulic presses, fixed upright on strong cast-iron bed-plates upon the top of the piers. The rams had 6 feet stroke, and carried cast-iron cross-heads, from which descended suspending chains attached to the tube below. The collective sectional area of the chains, which were composed of flat links 6 feet long, was 276 square inches; and the maximum strain they had to bear in lifting the gross load of 1,914 tons was

8·3 tons per square inch. The hydraulic presses being worked by steam power, the 6-feet lift took from half to three-quarters of an hour. Usually one lift was made per day, about a month being occupied in raising each tube to its final position.

While this mode of erection was adopted for each of the large tubes of 470-feet length, the shorter tubes for the two side spans of 230 feet were erected upon complete stagings, the two together containing 118,230 cubic feet of timber.

The four tubes in each line, though fixed separately in their places, had then to be united at their contiguous ends into one continuous girder. This was done by riveting their ends together, while the height of the temporary bearings supporting them was slightly varied, in such a manner that the ultimate result should be the same as if the continuous girder so formed had been erected throughout its entire length upon a complete horizontal staging.

The net cost of the whole of the appliances and labour for raising the tubes may be stated as follows :—

	£.
Pontoons, ropes, capstans, and lifting gear	37,880
Staging and cost of labour for erection, riveting, and raising	25,500
	63,380

The weight of iron in the bridge being 11,647 tons, this cost is equivalent to about £5 9*s*. per ton, which is not high, considering the novel difficulties that had continually to be overcome, and the absence at that time (1848) of any previous experience in this kind of work. It appears indeed remarkably low, when it is recollected that the construction of the tubes cost £19 8*s*. per ton for labour and general expenses alone; while the mean price of the iron employed, including both wrought and cast, was nearly £13 per ton.

This gigantic work marked an epoch in the progress of iron structures; and the mode of procedure adopted for its erection was not long in being imitated elsewhere, either wholly or in part. Saltash bridge was erected by Brunel in an exactly similar manner, its dimensions also being very similar; the two large spans are each 455 feet, and the height of the roadway above the water 100 feet. The railway bridge over the Weser, near Bremen, was erected in like manner in 1867.

Moerdyk Bridge.—The great bridge at Moerdyk in Holland,[1] on the Antwerp and Rotterdam railway, has lately been erected in a similar way, having fourteen openings of 328 feet, which are

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlv., p. 279.

crossed by semi-parabolic girders, with rigid vertical struts and flat diagonal braces. The depth of the river being in places as much as 43 feet at low water, and storms being of frequent occurrence there, the construction of a fixed staging was considered too hazardous to be risked; and it was decided to erect the girders out of reach of danger, and then to place them each singly over its own span. The mode of carrying out the work is illustrated in Figs. 7, 8, and 9, Plate 9.

At a shallow place on one of the banks two platforms were constructed upon transverse rows of piles, each row containing six piles 33 feet long, with 13½-feet spaces between the rows, except near the two ends, where two spaces, 200 feet apart, crossed by trussed beams, were left for the reception of the two pontoons by which the bridge girder was lifted and conveyed to its destination. On the platform was erected a light gantry for an overhead travelling crane, with the aid of which a girder 328 feet long and weighing 445 tons was erected by seventy-five men in ten weeks. The position of the girder while erecting was 15½ feet above low water, and the range of the tide is about 7¼ feet. The two flat-bottomed pontoons were each 115 feet long and 34 feet wide, drawing 3 feet of water under a load of 250 tons. They each carried a staging 7 feet high for lifting the girder from the erecting platform, and conveying it first of all to other supports near at hand, on which it was temporarily deposited, thus leaving the platform clear for starting the erection of the next girder. The staging on the pontoons being then raised about 6½ feet higher, the first girder was again lifted by them, advantage being always taken of the rise and fall of the tide; and was this time brought to its final resting place at the bridge piers. Here first one end of the girder and then the other was fixed in its proper position; and water was admitted into the pontoons to lower them sufficiently for letting the girder take its full bearing on the piers. The twofold operation of removing the girder from the erecting platform and placing it in position on the piers was not a long business; the whole was always accomplished within a single tide, and after a little practice the second half of the process was managed in as little as three-quarters of an hour.

It looks as though the lifting of the girders on the pontoons had here to no purpose been done twice over, instead of only once: first lifting it 2 feet for removing it from the erecting platform to its temporary halting place, and thence picking it up again a second time for conveying it to the bridge piers. This twofold handling however was not devoid of purpose, the weather being

in fact so seldom favourable for completing the whole operati at once; indeed the first girder that it was tried to transport in single shift ran the risk of being wrecked on the embankme against which it was driven by the wind. It was therefore oft necessary to wait some time till there was calm enough for doi the work with safety; and this time would have been all loss the girder had had to remain lying on the erecting platform, t men having then to knock off work, and perhaps leaving t premises. It was for this reason that the two shifts were decid upon for removing the girders.

In the drawing, one of the pontoons is shown in position un the girder, which of course had to be strengthened with timberi along the lattice work, as here shown, for preventing its bei thrown out of shape by being lifted at other points than permanent bearings.

Niagara Bridge.—Among other works that have been erected a somewhat similar way may be mentioned the Niagara bri between the United States and Canada, comprising a large num of openings, some 197 feet and others 248 feet span. Fixed stag was out of the question, owing to the bottom being rocky; and girders being discontinuous, as is the case in almost all Ameri bridges, could not be pushed across from pier to pier. A float staging was accordingly adopted, consisting of a rigid framew forming a platform, which was carried on either five or pontoons. The bridge ironwork was hoisted upon the platfo and as soon as the erection of that span was completed, water let into the pontoons, and they were withdrawn from underne the staging, which was left hanging to the erected girder, was afterwards removed in pieces, to be used over again erecting the next span.

The erection of bridges by floating the girders bodily certai presents attractive features, admitting as it does of large gir being constructed conveniently and in a safe situation, and their being afterwards removed thence and fixed in their tended position within the space of a few hours. Moreover favour of this mode of procedure it can be urged with m force that there is always good reason for endeavouring to work done in a convenient manner, and to diminish as fa possible the danger attending the operations. In the pres instance it may be objected that the danger is only shifted fi [redacted]tion of the work to another; and that the risk of dam

to fixed staging from floods and drift is here counterbalanced by the difficulty attending the operation of floating the finished girders. But it may with quite as much truth be replied that it is wise policy to concentrate difficulties at the fewest points, and to limit danger within the shortest time possible; much more vigilant supervision will then be exercised, and more careful precautions will be taken, the engineer-in-chief being most likely present on such occasions; and nothing will be left to take its chance, as has unfortunately been done with fatal results where operations involving possible danger have been prolonged through an extended period. In all these respects the plan of floating the girders presents features which make its more extensive adoption seem desirable.

The inconveniences attending it are mainly two. The first is that it requires the employment of a special gang of bargemen, accustomed to handling similar heavy craft on rivers, who are not everywhere to be met with so easily as in Holland or England, where every workman takes more or less readily to such work. The second inconvenience is that floating requires a rather considerable amount of plant, in the shape of pontoons, tugs, &c. On a very large work the outlay thus incurred is more than recouped; but for a small number of spans, or for light girders, it will be difficult to make the saving in cost of erection repay the expense of these additional appliances.

III.—Erection by Protrusion, or Rolling over of Girders.

Bridges with continuous girders extending over several spans have come into extensive use, particularly in France; and have given rise to a special mode of getting the girders into place by protruding, that is, pushing or rolling them across the tops of the piers from either end of the bridge. The convenience of this method has also in its turn frequently determined the design of the bridge. A principle is here involved which seems to be warranted by the results of its practical application: namely that the general arrangement of any work as a whole should be planned with an eye not only to its final purpose, but also to the means whereby it is to be carried out. In determining the course of a tunnel, or selecting the site of a station, this principle is fully recognised; and in the Author's opinion it is ordinarily of equal importance in the erection of iron bridges, while in certain exceptional instances facility of erection may even override all other considerations.

Fribourg Bridge.—The system of protrusion had its ori one of these exceptional instances, which occurred at Frib Switzerland, where the Sarine railway viaduct, built in 18 crosses a broad and deep valley on piers that are of mas the pediment and then of iron above. Staging would have be as high as 250 feet above the bottom of the valley; and, of the violent winds to which the valley is exposed, it w ventured upon. Instead of this, the entire length of the r was constructed on the hill, behind one of the abutments. wore then placed under it, and the whole was pushed forwards, projecting over the valley, until its front end ca the first pier, which had previously been built up to the top masonry pediment. Above this point the iron pier was the up to the top, by lowering the ironwork upon it from th hanging end of the roadway; and the top of the pier was back to the abutment by wrought-iron tie-rods, to prev capsizing when the roadway was again rolled forwards. timber framework was constructed on the top of the pier, t a fresh set of friction rollers, upon which the roadway w rolled forwards across the next span. The several piers we erected successively; and the opposite abutment having at been reached without excessive difficulty, it remained clear away the rollers with the timber frames that carried and to let the whole structure down upon its permanent bea

The rollers were of cast iron, 2½ feet in diameter, thei turning in wrought-iron bearings; in the erecting yard th spaced 66 feet apart. For moving the roadway forward them, windlasses worked by manual labour were fixed abutment, the chains from which were carried back and a to the tail end of the roadway. Exclusive of the time occu preparatory operations, which were performed while th were being erected, the actual forward movement of the r was effected rapidly, the distance of 160 feet from pier being crossed in six hours, with sixteen men at the crabs.

Stadlau Bridge.—A similar method was adopted for bridge at Vienna, crossing five spans of 232 feet each; th weight of the roadway that was rolled forwards was 2,1 and was moved twice. In the first operation three length was erected and rolled forwards over two op after which the entire length was completed, and the wh then rolled across. It was carried on sets of cast-iron 3 feet in diameter and 3 feet long, their length being equal width of sole of the girder booms; the rollers were arra

pairs under each boom, spaced about 100 feet apart from centre to centre, their necks being supported in cast-iron carriages 2½ feet high. On the front end of the roadway was fixed a plate-iron projection extending 100 feet in advance, so as to reach forwards to the next pier before there was a whole span overhanging of the roadway; thereby the pressure on the front rollers was diminished. At the back end a tail-piece 56 feet long was attached, for giving the finishing push to the roadway, as the windlass was here situated behind the abutment, to which it was strongly anchored. The hauling chain was attached underneath one of the main cross frames, which was suitably strengthened by horizontal struts. The speed of the winch handles was reduced 512 times by the gearing to the chain-barrel, whereby sixteen men at the windlass were enabled to advance the roadway from 13 to 20 feet an hour. The first protrusion, across two spans, was performed in eighteen working days; the second, over the three remaining spans but with the whole weight of the entire roadway, occupied twenty days.

From these particulars it is sufficiently apparent how low is the cost of pushing or rolling the roadway over in a work of this magnitude. On the most liberal computation the manual labour required for such an operation cannot be estimated at more than 20*d.* to 30*d.* per ton. The cost of the special plant needed is redeemed after a certain number of operations, and affects the total cost but little. It may thus be admitted that the cost of staging is almost wholly saved by this mode of procedure.

Where however the top and bottom booms and the lattice sides of the girders are not strong enough to support the overhang of an entire span, it becomes necessary to incur the additional cost of strengthening the girders, either by a permanent increase in the weight of metal put into them, or by the addition of temporary strengthening pieces. Of the latter the most usual are stays or ties, which support the extremity of the bridge by being strained tight over a trestle erected across the girders themselves. Notwithstanding the frequency of its adoption, this plan does not appear to ensure complete safety; it is somewhat expensive, and the fixing of the strengthening ties is attended with difficulty; and it still seems advantageous that the component portions of the girders should themselves be made slightly stronger, whereby at any rate the strength of the whole bridge will be permanently increased.

Waldshut Bridge.—Another method of protrusion was employed for the first time, to the best of the Author's knowledge, in 1859 at Waldshut railway bridge over the Rhine, in Switzerland. This is shown in Plate 9, Figs. 10 to 13, and is simpler and

cheaper than the foregoing. The windlasses are here repla by ratchet-wheels keyed on the roller spindles, and worked long levers reaching above the top of the girders; the up ends of the opposite levers are connected by crossbars, and rope extending the length of the bridge connects the whole the crossbars. The entire series of levers are thus worked together simultaneously by men walking along the top of roadway. This arrangement dispenses with the use of hauli chains or ropes, which are liable to give trouble by slacken suddenly, if from any cause the bridge happens to offer less res ance at any moment; irregular movements are thereby occasion which may become very serious. On iron piers, this mode working the rollers, whereby they are transformed from m carrying rollers into driving rollers, has another advantage, getting rid, to a large extent, of the tendency that there is to the pier over when the roadway is simply pushed across it ordinary carrying rollers. The importance of this advantage v be appreciated when it is remembered that piers have been knc to tilt up bodily on one side while the roadway was being pus across them, rocking back again upon their footings after movement of the roadway had ceased.

The shape of the rollers is not a matter of indifference. M commonly they are of cast iron, and their length is equal to the width of the sole of the girder boom, Fig. 13. But this shap inconvenient, especially for passing the steps that are formed the superposition of the successive plates in the sole of the bc The effective bearing too of the girder upon the rollers is lim to the middle of their length, just underneath the vertical we the boom. Hence narrower rollers are sometimes preferred, i porting the girder along only the middle of its width, Fig. 15.

Protrusion of the roadway upon rollers is attended with source of danger, in the concentration of the load upon a si number of bearing points; an excessive load may thus be thr especially upon the foremost roller, beyond which the end of bridge is all overhanging. Where the rollers are carried in f and unyielding bearings, it is upon the foremost that the gre part of the load comes. To obviate this objection, the rollers ca combined in groups of two or four, and mounted upon a rocl beam, singly or in pairs, as shown in Plate 9, Figs. 14 and The slight rocking movement of the beam upon a centre bea underneath ensures always an equal distribution of the between the rollers mounted upon it, however uneven be the of the boom bearing on them. This plan gets over all diffic

from the stepping of the plates and coverplates in the sole, and has been found to answer admirably in practice.

The advantages of this system of erection are palpable. The main work of constructing the bridge is carried on in safety and convenience upon the bank, and thus the circumstances under which it is performed are favourable to economy. The operation of pushing the finished roadway across the spans is attended with but little expense, and the plant used for the purpose can be employed over and over again in almost all subsequent cases. The process too is equally applicable to lofty viaducts and to bridges crossing rivers with low headway. Moreover very simple precautions are sufficient for dispelling all danger.

On the other hand, it has to be borne in mind that this mode of erection does not allow of much variety in the kind of bridge to which it can be applied. The bridge must be of the continuous-girder class, comprising at least two spans; the bottom booms of the girders must be of single or double ⊥ section; the lattice work must be close enough to prevent the bottom booms from bending to any dangerous extent, and also to render the lattice sides themselves strong enough for withstanding considerable strains of compression. Hence sometimes an excess of useless material has been put into the girders. Besides these there are also other disadvantages. The iron in the bottom booms is unquestionably strained by repeatedly passing over the rollers, the direction of the strains changing very suddenly and with great frequency; and the joints of the lattice bars are liable to be injured thereby. The utmost precautions are therefore requisite to obviate these objections, which unfortunately are not of a kind to be always perceived; and it is to be feared that under incompetent supervision parts so strained have been left permanently weak, involving the possibility of danger.

In several countries a strong reaction has set in for some years against the use of continuous-girder bridges. The opposition is based solely upon theoretical considerations pushed to an extreme; but is not likely to be diminished by the objections that have just been pointed out. The unfavourable opinion however is not shared in France, where bridges of this class continue to be built and protruded, without having thus far been attended with any accident.

Latterly this mode of erection has been pretty frequently applied to the particular operation of replacing existing bridges by new work in a very speedy manner. In Austria and Hungary there

are numbers of timber bridges, originally so built some twenty or thirty years ago with too great an idea of saving, which has ultimately proved bad economy. These are now one after another having their roadways renewed in wrought iron; but as they occur for the most part on lines having a large traffic, which could not be interrupted for more than a few hours, recourse has been had to the device of rolling the new roadway into its place sideways, the old work being either removed also in the same manner, or thrown down by being speedily dismembered. On the Oderberg and Kaschau railway in Hungary twenty-eight timber bridges, varying from 26 to 210-feet span, have been replaced in this way within a period of about twenty months, the work having been accomplished with complete success and without the slightest accident; and on the Northern railway of Austria a dozen spans at least have been so renewed.

Hernád Bridge.—As an illustration may be taken the bridge over the river Hernád, on the Oderberg and Kaschau railway, having two spans of 82 feet each. In the original timber bridge the rails were laid upon longitudinal beams, the underside of which was 46 feet above the river. The first step was to construct an erecting platform alongside the old roadway, at such a height that the new roadway should be erected upon it exactly at its intended permanent level, and at 20-feet horizontal distance sideways from the position it was ultimately to occupy. The construction of this erecting stage took twenty days; and at the same time under each span were erected two transverse rows of uprights to support a gantry with windlasses. The gantry was made of a couple of stout timbers, about 56 feet long, carrying a pair of rails of 13-inches gauge, on which ran small four-wheeled iron trucks, intended for shifting first the old timber roadway and then the new one of wrought iron.

Though the interval available between trains was so short, such good precautions were taken as to avoid any delay of the traffic. As soon as the old bridge had been crossed by the last train, its timber roadway was prized up on screw-jacks and the eight trucks were run in underneath its beams. This took about an hour, and five minutes more sufficed to run it off clear to one side, by means of the four windlasses with four men at each. A few stones, ready dressed beforehand, had then to be put in place for receiving the new roadway, the depth of which was not the same as that of the old. This also took about an hour; and meanwhile the trucks had been removed from under the timber roadway, and got under the new iron one, which was then run by them into its

place with five or six minutes' work at the windlasses. It was quickly lowered upon its bearings by screw-jacks, and the junction of the rails was readily completed, as the new roadway occupied exactly the place vacated by the old. The testing was immediately proceeded with, locomotives being in readiness for that purpose; and an hour later the regular trains were again crossing the bridge, after a total interval of about four hours. The weight of the iron-work in the bridge is about 68 tons; and including the permanent way and timber flooring the whole weight to be moved was about 90 tons.

Lomna Bridge.—In other instances however the work took longer to do. At Lomna bridge, of 102-feet span and about 70 tons weight, eleven hours were occupied in the operation, owing principally to the old timber work being in such bad condition.

Prater Bridge.—Another case that has only recently occurred of a similar operation may be mentioned, on account of the special appliances made use of. In the winter of 1879–80 the Austrian State railway had to replace one of the Prater bridges close to where the line crosses the Danube near Vienna. The new bridge carries two lines of way, and is 200 feet span, constructed of bowstring girders; it was erected on a staging alongside the old bridge, and at 18 feet distance from the position it was to occupy. It was carried on four transverse rows of uprights, by means of a live set of old cannon balls, which ran in the trough formed between an H iron below and an inverted channel-iron above them.[1] This device was due to Herr Weickum, one of the engineers of the line: and the horizontal web of the inverted channel-iron was stiffened by timbers above it, cut with their upper face bevelled, and bearing against a corresponding bevelled piece under the roadway, so as to form a wedge for conveniently lowering the load as soon as it was brought over its proper position. The lateral shifting was effected by hauling on tackle, by means of three windlasses fixed on the moving roadway itself. The whole weight of the roadway was about 350 tons, and it was shifted through the 18 feet in twenty minutes with four men at each windlass; five-and-twenty minutes more sufficed for lowering it on its bearings, and completing all else that had to be done for resuming the traffic.

Tornocz Bridge.—The work just described is the second of this kind that has been carried out on the same railway within a short period by means of the ball apparatus. The first was a single-line bridge over the river Waag at Tornocz, replacing a previous timber

[1] *Vide post*, p. 201.

structure. Here the weight of the new roadway was only 65 to
and it was shifted 18 feet in eleven minutes by four windlass
each worked by a couple of men.

The advantages attending the system of protrusion have led
its being applied in a somewhat different way: namely, not to t
permanent structure itself, but to the staging upon which the p
manent work is to be erected. In the case of a continuous-gird
bridge of several spans, and where the underside of all the girders
a straight line, it will most frequently be advantageous for the p
manent superstructure itself to be pushed across the opening
But where other considerations than convenience of erection le
to the employment either of discontinuous girders or of arch
ribs, the expedient may be adopted of constructing a continuo
staging, to reach over two spans, for instance; and of pushing th
across the two first openings, and erecting upon it the correspon
ing spans of the permanent structure; and then pushing it forwar
successively for the erection of the remaining spans one after anoth

Saint Just Bridge.—This was the method of procedure employ
for the erection of Saint Just road bridge over the river Ardèche
France, Plate 9, Figs. 18 and 19. The six openings, each 152 f
clear and 164 feet from centre to centre of the piers, are spann
by arched wrought-iron ribs, carrying a paved roadway of 23-f
width between the parapets. The river being liable to floods bringi
down boulders, and the headway being low, it was desirable
avoid encumbering the river bed with staging. The piers were fi
completed, and on the bank a rolling stage was constructed, co
posed of two timber lattice trusses, 28 feet apart and 18 feet de
connected to each other by timber cross-framing about every 1
feet, and stiffened between by gangways 4 feet wide running alo
the top of the top booms and alongside the bottom booms, there
helping to prevent their buckling. Along the top booms were l
rails for the travellers that lifted the materials. These timl
trusses were rolled across the spans on large rollers placed up
the piers and abutments, the rollers being arranged in pairs unc
each truss. Two openings being spanned at a time by this sta
the permanent structure erected by its means across the first sp
served, as soon as completed, to carry the component parts for t
second span; these were then taken by the travellers, by whi
they were lowered into position, and were temporarily suspend
from the underside of the timber stage, until each arched rib w
successively completed so as to support itself independently.
this way the five ribs in each span were erected, together wi

their cross-frames and other adjuncts; and no hitch occurred throughout the whole permanent structure, which contained 600 tons of wrought-iron work.

Regoa Bridge.—Another example of this mode of erection is presented by Regoa bridge over the river Douro in Portugal, Plate 9, Figs. 16 and 17. There are here four spans of 162 feet from centre to centre of piers, and one wider span of 263 feet. The height of the piers is 84 feet above low water; and as the river is liable to sudden floods rising as high as 72 feet, it was not deemed prudent to erect scaffolding. But as the design consisted of discontinuous girders on Schwedler's system, it was evidently impossible to do without some sort of temporary platform for erecting them upon. Recourse was therefore had, as in the preceding case, to a rolling stage, constructed of a pair of Howe trusses, 13 feet deep and about 322 feet long, so as to stretch across two of the smaller spans, with a triangular prolongation projecting beyond at each end. At the middle of their length they carried a lofty trestle, across which ran inclined stays supporting each overhanging half of the stage. The two side trusses were 30 feet apart centre to centre, allowing 26 feet width of pier between them, which was sufficient for erecting the permanent roadway of 22-feet width from centre to centre of its side girders; for its erection transverse frames were fixed across between the two timber trusses. The erection was commenced over the hinder of the two spans crossed by the movable stage; while the front half of its length had only to reach forwards across the next span at each shifting, and was therefore built much lighter than the hinder half, which had to carry the whole weight of the permanent structure in course of erection. The rollers carrying the movable stage were placed on ledges in the masonry of the piers; and to prevent the timber from crushing under the heavy load upon it, short wrought-iron bars were interposed one after another between the rollers and the underside of the bottom boom, as the stage was rolled forwards. Meanwhile the hinder or heavier end of the stage was suspended by small runners from the permanent roadway already erected, thereby preventing it from bearing with its whole weight on the after rollers. Motion was given by three winches on the piers.

The result was not altogether satisfactory. The timber available in the country was not of the best description, nor was the stage quite so well constructed as it might have been. Worst of all, it got very severely strained in protruding it across the successive spans, owing to the small depth of the trusses, which was

not more than one-thirteenth of their span; the direction of the strains was constantly changing as the protrusion proceeded, thereby racking the joints seriously. By the time the two first spans of the permanent bridge had been completed, and the third protrusion of the stage had to be performed, it was found necessary to abandon the trestle and tie-rods, and to erect instead an intermediate timber pier midway in each of the third and fourth spans. In the last and widest span of 263 feet, crossing the river channel, two intermediate timber piers had to be erected, for enabling the same stage to be pushed across and employed for the erection of this final span; after which the stage could not have been shifted again, having by that time become so rickety.

In this instance therefore experience does not seem very favourable to applying the plan of protrusion for getting temporary staging into place. It is only for exceptionally high bridges, or where the dangers of floods are unusually great, that it may be expedient to have recourse to this method. Even then, for ensuring the successful completion of the work, it will probably be necessary to aim particularly at great rapidity of execution, in order that the timber staging may hold out for the number of shiftings it has to undergo.

IV.—Erection by Overhang, or Building out.

The modes of erection already described have depended successively less and less upon extraneous appliances. Floating requires less plant than stagings; and protrusion still less. Erection by overhang, in which the permanent structure is made use of for its own erection, dispenses with extraneous appliances altogether.

El Cinca Bridge.—The first instance of a bridge erected on this principle is that of El Cinca bridge in Spain, having a single arch of 230 feet span across a very deep ravine, where it was difficult if not impossible to construct any staging. It was therefore decided to attempt erecting the arch by starting from each abutment and meeting in the middle. For this purpose the first portions of the springing on each side were securely footed to the abutments; while the end portions of the upper or longitudinal member, which was practically a horizontal chord, were tied back to cast-iron anchor-plates fixed behind the top of the abutments. The arched rib and horizontal chord were then prolonged outwards, panel by panel, by the successive addition of their several component portions, which were brought into position by a small crane

running on the top of the horizontal chord. Each half of the arch thus constituted during its erection a true cantilever or wall-bracket, standing out from the abutment. Underneath was suspended a light stage for the men putting in the rivets and bolts. As the distance between the abutments had been measured with great exactness, the junction of the two meeting halves was effected without difficulty. This first attempt at erection by overhang was rather costly; the weight of the bridge was 248 tons, and the cost of erection amounted to £2,200, or about £8 17*s.* per ton.

St. Louis Bridge.—Another example of an arch bridge erected in this way is the steel bridge over the Mississippi at St. Louis,[1] having two side arches of 502 feet span and a central one of 520 feet. As the depth of the river and the importance of the navigation precluded staging, each half arch was erected from the masonry piers, as at El Cinca bridge, but proceeding here on both sides of the pier simultaneously, so that the lateral strains should counterbalance one another, and leave only the vertical strain or weight of the structure to be borne by the piers as the erection progressed. Special arrangements were rendered necessary by the form of the arch, since the horizontal or longitudinal chord does not here constitute, as in the preceding instance, an essential member of the arch, and could not therefore serve as a tie to sustain it. The arched ribs were accordingly supported at various points by chains, which were carried over the top of skeleton towers rising about 125 feet above the springing of the arches. The tower was securely fixed on the top of the masonry pier by holding-down bolts, and 50 feet of its height was of timber. It really served only as a guide for steadying a pair of masts erected within it; and upon the top of these were fixed the cast-iron shoes over which the supporting chains passed. The feet of the masts were stepped into sockets upon the rams of two hydraulic presses, by which their height could be slightly varied; and the guiding tower allowed them to rock longitudinally, but not transversely. This provision was made with a view of preventing the portions already erected of the arches from being disturbed in position by the effects of expansion and contraction in the chains, which could thus be readjusted as required. The chains were composed of flat wrought-iron links, having eyes forged at their ends, and connected by bolts; the limit of working strain allowed was 5 tons per square inch. To equalise the tensions among the several chains, each was provided at the ends with right-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. li., p. 293.

and-left-hand adjusting screws. The attachments to the arcl ribs were made by girths, passing round the tubes of which ribs were composed. By these chains the arches were suppor at a distance of about one quarter of the whole span. Prior this point being reached, they were supported by secondary cha secured to the top of the masonry piers; these were removed soon as the main chains were fixed, and the latter were tl retained permanently until the two half arches met and w united.

The arched ribs were strong enough to stand being erected alc without the other parts of the structure, cross-ties, braces, &c., u the overhang reached about a quarter of the span; after which avoid straining the joints in the work already erected, the furt prolongation was again supported by secondary chains, pass over the top of a small timber trestle mounted across the arcl ribs at the point where the main chains were attached. Up to quarter of the span, the four ribs of which each arch was compc were all erected simultaneously; beyond there, the two middle only were first erected; and as soon as these had met and had b united, they were used for erecting the two remaining outside r

In each arch great difficulties were encountered in effecting junction of the meeting halves. In spite of all the care take determine at the outset the proper position of the ribs, non them met well. In one of the side spans, where a foot differe of level occurred, an attempt was made to bring the ends toge by taking advantage of changes of temperature, even going to extent of entirely covering the tubular ribs with ice. This an utter failure; and it became necessary to make the junctio inserting a piece prepared for the purpose, the length of wl was determined on fitting it into place in each of the ribs. centre span gave rise to no particular difficulties; but in the maining side span the same difficulties occurred as in the first, the junction was effected only through shortening the tubular pieces, and through the lucky chance of the temperature b lowered by a north wind opportunely springing up. The c frames between the ribs were fixed as the erection of the progressed; but the superstructure, comprising uprights and l zontal chord at top for the roadway, was not erected till after junctions of the arched ribs had been completed.

The financial results of this work were far from satisfac The estimates were exceeded by about 50 per cent.; and w other important causes also contributed to swell the excess, partly chargeable upon the difficulties of erection.

Kentucky Bridge.—Another very remarkable example of this kind of erection is afforded by the bridge crossing the river Kentucky on the Cincinnati Southern railway, a description of which has lately been presented to the Institution by Mr. T. C. Clarke, M. Inst. C.E.[1]

Douro Bridge. — The most recent example of erection by overhang is that of the railway bridge over the river Douro near Oporto[2]; and some particulars of this work may be of interest. The river, which is here too deep for the erection of any staging, is crossed by a crescent-shaped arch of 525-feet span, the height of the extrados at the crown being 200 feet above the water, Figs. 20 to 23, Plate 10. On the Oporto side or right bank are two spans of 94 feet, and on the Lisbon side or left bank three similar ones, all crossed by straight continuous girders resting on iron piers; the Lisbon abutment, owing to the gentler slope of that bank, is a rather taller one than the other, and is backed by an embankment from the hillside; the ground is granite rock.

Work was commenced in the spring of 1876 by constructing the whole masonry of the abutments and of the pediments for the iron piers, which latter were then erected, while at the same time the construction of the roadway girders was begun on the level behind the abutments. On completion the girders were protruded across the piers upon groups of four rollers mounted on a rocking beam, as shown in Fig. 14 previously described. The girders were made long enough to have an overhanging projection of about 105 feet each, beyond the piers from which the central arch springs. The hinder ends of the girders were anchored to the abutments and rock, for enabling them to withstand the forward pull of the temporary ties employed for sustaining the overhanging portions of the arch during its erection. On the top of the three intermediate piers the girders were temporarily supported upon wooden wedges; and on the two piers next the arch they rested upon sand-boxes, similar to those employed for striking the centering of stone bridges.

The foot or first segment of the crescent arch on each side of the river consisted of a plate-iron box-panel or caisson, for the convenient erection of which a narrow staging was constructed (March 1877) at the foot of the piers. The outer extremity of this panel, No. 1, was tied by a pair of steel wire-ropes T_1 to the hori-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. liv., p. 182.
[2] *Ibid.*, vol. li., p. 302.

zontal girder overhead, just above the point where the gir rested on the pier. It was thus prevented from capsizing dur the erection of the next panel, No. 2, which overhung the sn staging at foot. This second panel is of lattice make, with cr braces and transverse framing between its two sides; and completion its outer extremity was tied by a fresh pair of w ropes T_2 to the same point on the top girder to which the f pair T_1 were attached. The two next panels, Nos. 3 and 4, w then erected overhanging; and the first pair of ropes T_1, hav already been superseded by T_2, were now removed to T_3 at outer extremity of No. 4 panel, and were tightened up as much possible. The next panel, No. 5, is made shorter and stron than those preceding, as it has to carry the intermediate dw pier for supporting the roadway girder from the haunch of arch. On the completion of this No. 5 panel, its outer extrem was supported by removing the ropes T_2 into the position T_4; s the two sets of ropes T_3 and T_4 together now gave support enou for erecting the three next panels overhanging—Nos. 6, 7, and Thus far all the panels were erected complete with the whole their component pieces; but to avoid having too heavy an ov hanging load, the two next panels, Nos. 9 and 10, were at f erected incomplete, omitting temporarily the top boom or extra and a portion of the diagonal braces. The bottom boom projec about 7 feet beyond No. 10 panel; and it then only remai (30th of August, 1877) to insert the junction piece at the cro for uniting the two meeting halves of the arch.

In relation to the horizontal centre line of the bridge, it v found the work had been erected so accurately that there was material deviation laterally at the meeting ends. Vertica however both ends were about 14 inches too high, and the g between them was consequently too wide. This was intentior Owing to the supporting ropes being shifted successively to d ferent points in the arch as its erection progressed, and owing a to the mode of putting together the several component parts the arch, it was felt that, in spite of very careful calculatio there must be some uncertainty as to what would be the act height of the ends of the two half arches. If they should prove be too low, it would be almost impossible to raise them. It w therefore deemed prudent to erect the work in such a manner should ensure their being a little too high; and to make provisi for then letting them down to meet each other. For this purpc the end fastenings of the wire-ropes supporting the arch we carried upon cast-iron wedges; and as soon as the correct positi

for the arch ends had been determined, and the width of the gap had been measured, each half arch was gradually lowered, by easing the ropes with the aid of hydraulic jacks, and withdrawing the cast-iron wedges one by one. In this way the two meeting ends were adjusted exactly to the required position for the insertion of the junction piece, which was put into its place without difficulty, by taking advantage of the slight variations resulting from changes of temperature.

Had the full load been left on the wire-ropes after the junction was effected, there was reason to fear lest even a slight fall of temperature might have occasioned unforeseen and injurious strains upon the arch as a whole, and particularly upon the junction piece which was so much weaker than the rest. Accordingly, as soon as ever the junction was completed of the intrados, the ropes were immediately slacked out, this time by means of the sand-boxes under the roadway girders. By letting the sand run out for ten to fifteen minutes, the fastenings at the top ends of the ropes were lowered sufficiently to ease the ropes of a portion of their load, while still leaving them tight enough to relieve the junction piece at the crown from part of the strain which would otherwise have been thrown upon it.

The erection of the extrados and remaining lattice work was then completed in the panels at the crown of the arch; after which the dwarf piers on the haunches were erected, and finally the central length of the horizontal roadway girders.

Turning to some of the details connected with the erection of this work, the anchorages behind either extremity of the horizontal roadway girders were made with four flat wrought-iron tie-bars, which were tightened up by cotters bearing on cast-iron sole-plates bedded against the masonry of the abutments. At the Oporto end, where the abutment ran back into the granite rock, the tie-bars were nearly horizontal; but at the Lisbon end the smaller abutment, not being heavy enough to stand the pull, had to be backed with a large mass of masonry, through which the tie-bars were carried down obliquely to the sole-plates bedded behind it at the bottom.

The steel wire-ropes employed for supporting the arch during erection were each composed of six strands, each strand containing nineteen wires of 0·1055-inch diameter (No. 12 B.W.G.); the sectional area of each rope was therefore 1 square inch. On testing them beforehand, the breaking strain was found to be not less than 80 tons; and as they were never strained beyond a pull of 12·7 tons, the minimum factor of safety in working was six times.

The mode of fastening the ends of the wire-ropes is shown in Plate 10, Fig. 24. The end of the rope was passed through a conical hole in a wrought-iron block, and the separate wires were opened out in the form of a brush around a hollow wrought-iron cone, inside which their ends were turned over, and secured by filling it up with hard white-metal. The fastening thus made was stronger than any other part of the rope, which always broke elsewhere in the testing.[1]

The attachment of the wire-ropes to the arch was done in a very simple manner. The top-boom, to which the attachment was made, was of inverted channel section; and beneath its flanges was placed a rounded shoe, shown in Fig. 25, under which the rope merely passed in a continuous length. The rope was thus double at each point of support, both its ends being secured by the fastenings above described. There were thus in reality four ropes supporting the arch at T_1 and four at T_2; while at T_3 and T_4 each rope was again doubled, making altogether sixteen ropes at these two places jointly.

The attachments of the upper ends of the wire-ropes were arranged in the following manner. In the horizontal roadway girders the panels immediately over the piers have plate-iron sides, which were further strengthened by triangular plates were stiffened with angle-irons. To these again were fixed, both inside and outside the girder, double cantilevers, carrying two pairs of transverse beams of H section, built up of a centre web and four angle-irons. Each pair of beams carried eight rope-ends, for supporting the haunch of the arch at T_3 and T_4. Each of the wrought-iron blocks in which the rope ends were fastened bore upon the beams through a number of cast-iron wedges inserted beneath it. These wedges were for the twofold purpose of adjusting any slight inequalities of length in the several ropes; and afterwards of letting the ropes out gradually in succession, by withdrawing the wedges one by one. The two first sets of ropes, supporting the springing of the arch at T_1 and T_2 and having a much lighter load to carry, were not fixed to the same beams, but to another beam similarly placed across the top of the roadway girders. No alteration was thus required in the length of the ropes on transferring them from their first to their second positions.

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[1] A similar method, adopted from the practice of American engineers, was employed for fastening the ends of the steel wire-ropes in a movable suspension bridge at the Landore Siemens-Steel Works. (See Institution of Mechanical Engineers. Proceedings 1870, p. 252.)

For slacking out the ropes, a pair of 100-ton hydraulic jacks were applied, one at each side of the wrought-iron block on the rope end, to which they were connected by crossheads and coupling-rods. On working the jacks they relieved the load off the cast-iron wedges under the block, one of which was withdrawn, letting the block down an inch or two to bear upon the rest. The jacks were then shifted to the other end of the same rope, which was let out to the same amount. In this way the entire half arch supported by the ropes was successfully lowered to the extent desired, without jerk and without undue strain on the ropes.

The sand-boxes supporting the roadway girders on the top of the pier were simply large sheet-iron cylinders, full of fine dry sand, on which rested a wood block of rather smaller diameter than the cylinder; the sole of the girder bore direct on this block. By letting the sand run out, the whole of the ropes were slacked simultaneously and equally, with perfect steadiness, and much more speedily than in the previous successive slacking of each separately by means of the jacks and wedges.

In getting the separate pieces of the arch successively into position for joining to the portion already erected, considerable difficulty was experienced, owing to the varying width of the arch itself, which is nearly 50 feet at the springing and tapers to only 13 feet at the crown. A steel wire-rope was first of all stretched across the river, mounted like a suspension-bridge chain upon trestles erected on the top of the nearest piers. On this rope travelled a little pulley carriage, drawn backwards and forwards by a windlass at each trestle; at the same place were the hoisting windlasses, from which the lifting rope passed over the travelling pulley down to the boat containing the materials to be hoisted. As the bridge-rope overhead hung in the centre line of the roadway, there was considerable difficulty near the springing of the arch in reaching joints situated 23 feet to the right or left of this line. Towards the crown, where, though the width of the arch was less, the lifting rope was so much shorter as to be thrown still more out of the perpendicular, recourse was had to another mode of raising the materials, by a sort of wide-straddling derrick, with its legs nearly as far apart at top as at bottom, and adjustable to the varying width of the arch. This was rigged up on the extremity of the extrados already erected, and was held in position by back stays. The hoisting rope passing over it was worked by a windlass in the foot of the iron pier at the springing of the arch. These derricks were themselves dismounted and re-erected by means of the travelling pulley on the overhead bridge-rope.

From the foregoing description it will have been gathered how carefully all the circumstances arising in the progressive erection of the bridge had been considered beforehand, so as to leave the least possible room for anything unforeseen. The result has been completely successful. The work was not done expeditiously, but under conditions which ensured great safety. Excepting the loss of one life, no accident occurred throughout so many dangerous operations.

Concluding Remarks.—From this review of the different modes of erection, a progressive tendency seems clearly traceable in the successive methods employed. The old-fashioned rut of servile imitation from stone structures has gradually been abandoned for modes of erection in which the permanent structure is utilized for the preliminary work from its very outset. This implies taking accurately into account, in designing any work, all the stages of its progress. And although the first of these stages, namely its construction, occupies the shortest time of all, it is none the less the one which most affects the economy of the work, and in many cases its safety and durability. It thus becomes with good reason one of an engineer's principal aims, to attain—in combination with strength and elegance—simplicity, facility, and economy of construction. It is this aim that has led, in France more than in other countries, to the use of continuous girders, the erection of which is at the present time one of the least costly. It may however be observed that, exceptional cases apart, iron bridges of all kinds, from arched bridges to lattice swing bridges, admit of being erected without the use of auxiliary girders or staging. Under good management it seems likely that such independent modes of erection will most frequently prove economical; and it is to be hoped that, in the execution of engineering works, antiquated routine may be superseded by scientific methods, having both reason and elegance in their favour.

The Paper is accompanied by a series of small-scale drawings, from which Plates 8, 9 and 10 have been engraved.

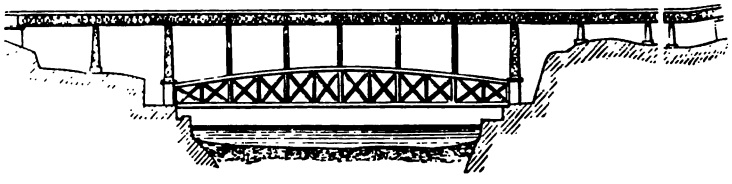
Discussion.

Mr. TH. SEYRIG said he did not pretend to have sketched completely in his Paper the different modes of erection of iron bridges. It might almost be said that there were as many modes of erection as there were systems of iron bridges; and these had been very numerous, especially during the last few years. But he thought there was much use in classifying, as it were, the different modes of erection; and it was merely towards that point, and towards showing that theory might have a useful bearing on this essentially practical part of an engineer's work, that his efforts had been directed. He thought there ought to be more foresight or forethought in the getting up of designs for iron bridges than had generally been shown; and it would not be difficult to mention instances in which the erection of a bridge had been not only more costly, but also more difficult and dangerous than the work itself. It was this point to which he desired particularly to direct attention, that the design of the bridge should demonstrate the process or the theory of the way in which it ought to be erected. He might be permitted to exemplify what he had stated by the most recent example. The members had before them the successive stages in the erection of the Douro bridge, which he believed was the largest of its kind, though a larger one was now about to be built; and a few weeks ago there was a competition for another bridge near the same place of a considerably larger span. The bridge represented in Plate 10, Figs. 20 to 23, was of 525-feet span, and the new bridge was intended to have a span of 571 feet; and as every engineer knew, the difficulties with such large spans were not simply proportionately, but far more than proportionately greater as the length increased. A certain number of plans were given in for competition; the tenders were very different in price; he did not propose however to call attention to that point, but rather to the different ways in which the problem was proposed to be solved. The principal difficulty in this second Douro bridge was the same as in the first, that no intermediate staging was possible for spanning the river. Not only was the water deep, but the ground was insecure. The depth of the water was 40 feet or more, and the ground was very shifting. Moreover the tide came in twice a day to a certain height, which rendered it inconvenient to work there; and there were very high floods to be feared. All those conditions might make it difficult, if not impossible, to erect staging; and one of the other modes of erection had to be resorted to. He believed that all the plans proposed

Mr. Seyrig.

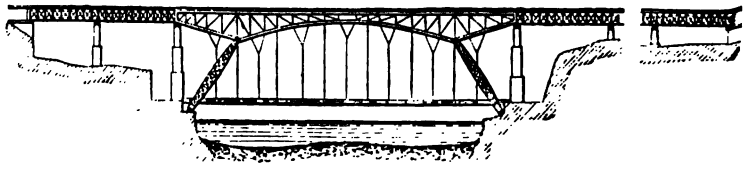
Trig. bore evidence of this difficulty. He would sketch three of the proposed plans, and thus show how necessary it was beforehand to pay attention to this particular difficulty; and the different ways in which the problem was proposed to be solved would the better illustrate the necessity of forethought in design. Two roadways had to be provided, one above, and one below; one establishing a communication between the upper, and the other between the lower parts of the opposite townships. The lower roadway was to cross near the level of the river, and the upper about 160 feet higher. In one of the plans proposed it was evidently the intention of the designer to do the work by floating (Fig. 1). There was a semi-parabolic girder resting on the lower

FIG. 1.



abutments, divided into panels by verticals, as was usual in bowstring girder; on this girder were erected standards to supp the upper roadway. The girder was evidently intended to erected somewhere up the river, and to be lifted bodily a brought into position by barges or pontoons placed underneath That plan was, he believed, one of the most costly in this ca owing to there being only one span to erect; although in consequen of the lightness of the girder, the firm proposing it were able bring down the price to one of the lowest. Another plan (Fig. 2

FIG. 2.

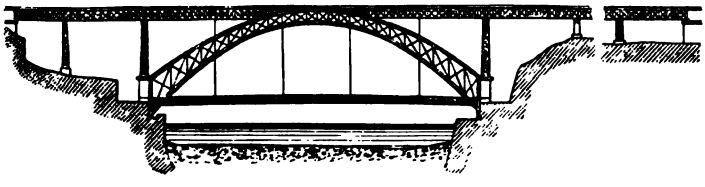


was this: the piers were to be first erected on the banks of the river; the roadway was to be constructed as far as the piers, and alongside of them was to be erected temporarily another kind of pier, consisting of a standard or strut braced to the first pier. A place for it would easily be found in front of the abutments on which the main pier rested. These constructions had evidently

tability enough to resist the wind and all other extraneous forces during the erection. It was proposed then to lower these huge struts, letting them turn upon their lower end as a centre, and at the same time to build up successively parts of the top girder, which after the lowering of the struts was to become a chief girder of the bridge. When once they had come into their required inclined position, they were already attached to the upper portion by a piece of girder having the form of a tie. It was not difficult to see how that part of the girder could be built up as the strut was lowered; and when once that point was reached, the upper part was stable in itself, forming a cantilever. The cantilever being sufficiently fixed to the abutment and to the roadway girders extending behind, it was evident that an arch could be built forward, piece by piece, so as to reach the middle of the bridge, and thus construct a true arch, and form, with the part built as a cantilever, a structure the resistance of which might be accurately calculated. The third plan, which was his own (Fig. 3), was very

Mr. Seyrig.

FIG. 3.



similar to that of the first Douro bridge, with one slight difference. A difficulty had been experienced in that bridge from the arch resting on its abutments in a point; and one of the greatest difficulties, small as it might now seem, had been to support the first, second and third panels securely during erection. There was but a small space available for the staging employed for the purpose, and the plan now proposed for the new bridge to be built alongside the first one was to make the arch proper not with a pointed toe, but with its abutment ends deeper than its crown. It was thus evident that three, four, or more panels—the heaviest in the arch—could be got into place more securely, and probably at less cost, than even with the very little staging and the ropes which in the former bridge were made to support them. The form of the new arch might also perhaps be considered more elegant, and to some extent it might be regarded as an improvement. These three examples would show that the difficulties of erection in special cases ought to be as carefully considered as the question of the resistance and ultimate working strength of the bridge itself.

artineau. Mr. WILLIAM MARTINEAU said as he had been concerned for one of the parties tendering for the original Douro bridge (the only English firm, he believed), and had seen all the designs submitted, he might be permitted to supplement the remarks of Mr. Seyrig by saying that there was another design from a French house, which was composed of two slight curved arches, representing as it were a Gothic arch, forming two flat curves falling together in the centre. No very clear explanation was given as to how that bridge was intended to be erected, but he should infer that it was in the way which Mr. Seyrig had illustrated—by building upright struts and gradually lowering them together. The design submitted by the firm for which he was concerned was a semicircular arch for the centre, and two side arches, also semicircular. They were intended to be erected as cantilevers, half on one side and half on the other, counterbalancing each other until arriving at the centre. The width of the bridge was about 18 feet at the top, spreading out much wider at the bottom. There was one ponderous plate-girder bridge which he presumed was intended to be raised by hydraulic pressure.

r. Lloyd. Mr. S. ZACHARY LLOYD wished to give a few particulars of the erection of a bridge in Spain, over the river Esla, with which he had been connected some years ago on the Palencia and Ponferrada railway. Nothing of the kind, he believed, had been mentioned in the Paper. It was a peculiar mode of erection, which, he presumed, would not be frequently employed. The bridge (100-feet span) was riveted up complete at the railway terminus, and a double bogie truck, with four ordinary wagons, was run under each end. The bridge was thus carried down the line a distance of 50 miles, run over a temporary bridge, and then lowered into place. It was a simple arrangement, and answered very well; but in most cases a temporary bridge would probably be far more expensive than was desirable. Another bridge on the line had been erected much in a similar manner, under the superintendence of Mr. Oudry, a French engineer. Of course there were no bridges across the line, and no tunnels; and there were very few cuttings, and in one only of these was any difficulty experienced. Each span was 150 tons in weight.

. Wawn. Mr. C. WAWN had listened to the Paper with considerable interest, having been concerned in the erection of several bridges. He could have desired, however, that some more of Mr. Seyrig's examples had been taken from this country, such, for instance, as the Clifton suspension bridge or some of the bridges over the Thames. He observed that in the Königswart bridge the scaffolding was

ained 10 tons to the inch. He considered this rather a severe Mr. Wawn.
ain even for a temporary purpose. His own experience was
t temporary works, which were not generally so carefully
sidered in detail as permanent structures, were occasionally
posed to unexpected shocks from accidents to cranes, &c., and a
ain of 10 tons to the inch (too much in itself) certainly left no
argin for such contingencies. It was stated in the Paper that,
rolling out a bridge, considerable side strain was thrown upon
e piers. That might be obviated by taking a tie from the top
f the pier exposed to the thrust, and attaching it to the press or
ab, or whatever was used for giving motion to the bridge, so
hat the strains might be self-contained. There was another
ethod of rolling bridges to which reference had not been made—
compromise between rolling over and floating. The girder was
irst thrust out about a third of the way across, a vessel was
rought under the end, which was lifted by taking advantage of
he rise of the tide, or by pumping water out of the vessel to get
lotation. The girder was then drawn over, one end supported by
the vessel and the other by the pier. It had been stated that it
was necessary in rolling out that the girder should be continuous.
This was not necessary in all cases; indeed he had been con-
sidering the question lately, and a scheme had suggested itself by
which, in the case of a single opening crossed by three girders (say
for a double line of rail), the centre girder could be made to carry
over successively the two outer ones. Two girders were built on
opposite sides of the opening, and each rolled halfway out, meeting
in the centre, as shown in dotted lines in Fig. 4, and being
temporarily fastened together they were drawn over as shown in
Fig. 5. The attachment was made preferentially by a pin or

FIG. 4.

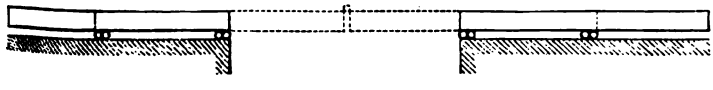


FIG. 5.

inge, in order to provide for the slight vertical motion due to the
mber of the girder. As the girders advanced, the weight to be
rried by the supporting girder of course increased, but was more

Wawn. than balanced by the greater leverage of its inner end. A girder rolled over in this way, being cantilevered for only half its length, must be less subject to injury than if thrust out for its whole length, counterbalanced by a temporary tail-piece. After the two outer girders were in place there could be no difficulty in getting the third over. The system of rolling over, which he had sketched, though not universally applicable, might in a modified form be of use in many situations.

Matheson. Mr. E. MATHESON said as reference had been made to the Kentucky bridge, described in a previous Paper by Mr. Clarke,[1] he might be permitted to say a few words about it on the question of erection. It was, he believed, the longest length of building out ever attempted, having been built forward 196 feet. He had recently brought with him from America, and now exhibited, photographs showing the state of things when the building out was at its greatest. The girders were not pushed forward. A suspension bridge, towers, and anchorage had been constructed, and the anchorage was made use of to hold down the girders, allowing the extreme building out. The height over the water was 275 feet, so that a staging below was almost impossible. A light trellis however was put up to carry the point of the bridge when it got to 196 feet, and it was then thrust forward to complete the span of 375 feet. One strange point was that no advantage had been taken of the towers, as in the Douro bridge. No suspension was attempted; the ends of the girders were merely anchored down, and the building carried out from them. He did not know of any other bridge built out so far in that way.

Reeves. Mr. F. W. REEVES observed that, although the Author had classified the different modes of erection in a somewhat arbitrary manner, his Paper would be of great service to those who might have anything to do with similar kind of work. It had been stated that when the bridges were rolled over they were liable to injury; two cases of that kind had come under his own notice but in no case had there been anything more than a temporary delay. The first instance was that of a bridge with a continuous girder and two spans of 170 feet. The bridge was not strengthened for rolling, but, in order to give it a sufficient vertical stiffness during the rolling, temporary struts of wood were introduced. When the girder, which weighed about 350 tons, was nearly at the central pier, the struts yielded, and some of the hinder bars were bent beyond the limits of elasticity, and had to be taken out and

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. liv., p. 182.

tened. The work was carried on however with very little Mr. Reeves.
ınd was ultimately successful. The other case was that of a
across the Tagus, consisting of nine spans of 130 feet. While
the spans was being rolled, the boom was not only damaged
ctured, and a temporary pier had to be erected to support the
the girder while the broken piece of boom was cut out and
d. There was a delay in that case of about three months.
floating could be resorted to, he believed that was the
st way of getting bridges into their places. It might be
ive to make special plant for a few spans; but if they were
y large, ordinary craft, lighters, barges, or even ships might
t cases be used for the purpose. He had seen two or three
ıts in the lifting of ironwork, and he would recommend the
iron links where they could be employed. It would have
ıteresting if the Author could have given the approximate
the erection of the Douro bridge.

G. Wells Owen having, in conjunction with Mr. G. W. Mr. Owen.
g, M. Inst. C.E., carried out the large bridge over the Severn,
l to say that, from the first moment of the inception of the
, careful attention had been paid to the manner in which it
have to be erected. The whole of the scaffolding and the
of erection had been designed and arranged by themselves.
ridge consisted of several spans varying from 134 to 171 feet,
ro spans of 327 feet. The difficulty only arose, of course, in
ıce to the large spans where the bed of the river was tolerably
ınd contained a considerable amount of sand. As the Bill
Parliament, the intention had been to build the two large
ı as a continuous girder, of about 650-feet length, on the
ry viaduct that connected the main bridge with the shore, and
them over the one small iron span that intervened between
ınd this viaduct; it was found however, on careful calcu-
that the extra amount of iron necessary to brace the girders
ır to roll them across such large openings without crippling
would have involved so great a cost that the idea had to be
ıned. The consent of the conservators of the Severn was
ards obtained to build two temporary piers somewhat
: to those shown in Fig. 16, carrying a timber superstructure
rhich the girders were built up *in sitû*.

H. N. Maynard had been a good deal connected with Mr. Maynard.
-making, and had given much attention to the question of
-over bridges. His firm had constructed the Crumlin
t, and, calculating the size required for the girders, they
d a span of 150 feet, and had the girders lifted from the

Maynard. valley. The height of the bridge was about 200 feet, and it consisted of ten spans. The ordinary mode of lifting by a crab and pulley blocks had been adopted. The girders were erected at a cost of about 10*s.* per ton for labour alone, and a considerable sum was spent in the preparation of tackle. A girder was lifted by a gang of twenty men to the height of 200 feet in one day, and it required the same men double that time to prepare the tackle and build up the girder. The cost of the entire erection was about 30*s.* per ton, excluding the cost of tackle. The cost of the tackle was divided over the whole work. Had there been only one span, the cost per ton would of course have been larger. In another case, where the bridge was a single span of 150 feet at a considerable height, weighing a little more than half as much again as a span of the Crumlin viaduct carrying a similar load, the girders were rolled forward singly to overhang 70 feet, a floating stage taking the overhanging end, and the bridge was erected partly by lifting and partly by flotation. Here the tackle had cost as much per ton erected as the entire erection of another bridge of a similar span, because it had to be divided over one span only. He agreed with Mr. Seyrig and Mr. Owen as to the importance of following out the design of the bridge from the beginning to the end. If the plan of rolling over had been adopted for the Crumlin viaduct, it would have been necessary to use girders 50 per cent. heavier than those employed. The actual rolling over might in some cases cost very little; but then it was necessary to consider also the additional iron required to be put into the girders to make it possible to roll them over. The cost per ton in the case of the Stadlau bridge was stated to have been from 1*s.* 8*d.* to 2*s.* 6*d.* per ton; but nothing had been said as to what additional iron was required to make the bridge capable of being rolled over, or as to the cost of the necessary tackle. In some of the examples cited the cost of the staging was excessive, while in others it was perhaps very low. In the case of the Znaïm viaduct the cost was said to have been £3 12*s.* per ton. He had himself erected in Italy two viaducts, one being 95 feet and the other 140 feet high, each with five spans of 120 feet with continuous lattice girders, weighing together 422 tons. The scaffolding was similar to that described by Mr. Seyrig. The cost was £1 9*s.* per ton. Allowing the timber to be worth half the original cost, the use and waste of it amounted to 7*s.* 6*d.* per ton more, so that the total cost was but little more than half of that for the Znaïm viaduct. Of course there was a great difference in the cost of the erection of similar structures in different parts of the world, and it was impossible to state what constituted

e elements of difference. A large margin had to be allowed for ntingencies which could not be described. In the centre of frica, for instance, all sorts of difficulties would have to be conded with, and labour would be more costly than near the coast. Mr. Maynard.

Mr. JOHN DIXON remarked that each bridge should be specially vised for the circumstances to which it was adapted. The ouro bridge was perhaps the most striking of any of the amples cited; but the drawing gave a very inadequate idea of e extent and imposing character of the work. Considering that e span was 525 feet, the height above the river 180 feet, and at the bridge with its approaches was carried across the ravine r £49,000, the French engineers deserved every credit for the kill manifested in the design, and for the strikingly imposing ect of the structure. Those who had watched it from inception nd through the various stages of erection, as he had done, could ot but accord to Mr. Seyrig, who had had the chief control and esign of the entire work, great praise and credit for the manner in hich it had been carried out. It had often struck him, looking t the examples of bridgework on the continent, that they somehat reflected the popular idea of the different types of national haracter. The French works, for instance, were of a light and iry character, as contrasted with the more substantial works to hich English engineers were accustomed. The latter did not esign such light structures, but they could not fail to admire hem when executed. He might be permitted to suggest that he Author should add to his Paper a few more statistics as to he cost of the erection of the bridges with which he had been onnected. He would also draw his attention to the well-known iaducts on the Orleans line, where the girders had been rolled cross high piers in a very economical way. In every instance of olling girders forward that had come under his own notice, the work ad more or less suffered by the excessive strain thrown on the ifferent parts of the lower members, which were not especially alculated to bear it. In many cases absolute injury had been stained, and he did not think the system should be followed if could be avoided. The Institution was greatly indebted to a ember of the French engineering profession (which had carried gineering science to a state of such perfection) for coming to ngland to read a Paper on so interesting a subject. Mr. Dixon.

Mr. A. BUCHANAN, like other speakers, felt a debt of gratitude the Author for having brought the matter before the members the way he had done. He agreed with the statement that the per exemplified the fact that almost every bridge should be Mr. Buchanan

uchanan. treated in accordance with what the circumstances of the ca would admit of. He believed that, as a rule, English enginee recognised the necessity of considering from the beginning ho a bridge should be erected. In erecting a bridge, at all events in foreign country, an engineer should do the best he could wi the labour and materials at hand; and it was not always possi absolutely to determine the best plan until arriving on the sp He might design a bridge at home, in the expectation of findi many things in the country to which he was going, but whi were not to be found there. Generally speaking, he believed t differences in the cost of erection were not so great as so persons imagined. In the centre of Africa the difference might considerable; but in most semi-civilized places the cost of lab was much less than in civilized countries; so that by usin greater proportion of labour very nearly the same result might attained. Some of the viaducts to which reference had b made would appear to have been built in countries where tim was tolerably cheap. In countries like England an endeavour generally made to economise in timber structures, in order secure a lower cost. It would not however be right to be critical, because the best might have been done under the cumstances. The Douro bridge was peculiarly interesting; the way in which every advantage had been taken of the struct itself, in order to erect it, might be taken as a model. In the e tion of heavy work, especially away from home, it was of g importance to consider the joints by which the various portion the bridge were put together. If they were not thoroughly fully considered, immense trouble would be occasioned in erection, and there would be great risk of the structure get seriously damaged during its transit. If there were long hanging light pieces, which were difficult to pack and pr satisfactorily, they would be pretty sure to arrive at their des tion to some extent damaged, when it might be found impos to replace them; and the bridge might consequently be put a crippled condition. In such cases, perhaps above all ot the advantage of erecting on a staging was realised. Of c in such a case as the Douro bridge a stage ought not to be but where it could be employed it was very desirable. I Moerdyk bridge, the use of pontoons to float the girders combined the advantage of building upon a stage with pu over. The principal gain in building upon a stage consist making it possible to preserve the exact "camber" of the g and so to avoid the enlarging of holes and other alterations

structure due to loss of "camber." This seemed to point to the great advantage of using a stage where it could be employed with anything like economy. Equal advantages could hardly be expected to arise from the pushing-over plan, especially with girders which were not continuous. The plan of putting a bridge together at a railway terminus, and conveying it to its destination in one piece, was a very nice one when it could be carried out; but this was seldom possible. A number of pieces might be carried on successive trucks for hundreds of miles (as had been done in Russia), and the whole span could be put together on arriving at the site, the trucks being used as a stage. When the bridge was thus firmly put together it was pulled over a temporary structure at the place where it was to be finally deposited; and when the trucks were removed, it was lowered into place by tackle. Mr. Buchana

Mr. G. H. PHIPPS said that, having had to consider the same subject as the present Paper in some lectures which he delivered seven years ago at the School of Military Engineering at Chatham, he could quite appreciate the great trouble to which the Author must have been put in preparing so excellent an account of works as his Paper contained. He should have been glad however if the Engineers who at early periods had executed some of the works in question had been mentioned. He should like to mention the name of his friend, the late Mr. J. M. Heppel, M. Inst. C.E., who, in 1858, 1860, 1867, and 1870, employed the pushing-over principle on the Palar river, the Cauvery, the Chittranutty, and the Ganges, at Cawnpore. In the last case the rollers were caused to revolve by mechanical power; and in order that all the rollers, ten on each pier, should take an equal bearing, they were kept up by hydraulic pressure all in connection, so that no one roller could have more than its due share of pressure, and this he thought was a very great improvement. He might also refer to a bridge that had been put up in the Mauritius by Mr. Longridge. He had previously remarked upon the beauty and arrangement of the Fribourg bridge:[1] not only were the girders pushed over the piers, but the latter were built in place from the extremities of the girders when overhanging the abutments. He might also allude to Mr. Berkley's Mhowke Mullee viaduct, the girders of which were lifted bodily into place by hydraulic apparatus. An admirable Paper had been read by Mr. Leslie on a bridge over the Gorai river,[2] Mr. Phipps.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxv., p. 250.
[2] *Ibid.*, vol. xxxiv., p. 1.

Phipps. which was partly floated and partly pushed into position. Nothing had been said in the Paper about the erection of suspension bridges; but perhaps the Author thought that was too wide a range to take. Great credit was, he thought, due to the late Mr. Price Prichard Baly, M. Inst. C.E., who had arranged, under Mr. Brunel, the system of wire ropes for erecting the Hungerford Suspension Bridge. When it was removed to Clifton by Messrs. Hawkshaw and Barlow, wire ropes were also successfully used. He thought that more use might be made of them in erecting bridges than had hitherto been done.

Barry. Mr. J. WOLFE BARRY did not understand why such large spans as 227 feet should have been used in the Königswart viaduct. The water-level evidently was sufficiently low to admit of temporary piers being erected, and he wished to ask why permanent piers had not been adopted there also. A similar question might be asked in reference to the Znaïm viaduct, where the spans on each side of the water-channel were 164 feet. Perhaps some calculation had been made to prove that they were more economical than smaller spans; but at first sight it appeared that, while one of the centre spans of 197 feet was correctly proportioned, the side spans were not economical. He also desired to direct attention, in the case of the Znaïm viaduct, to the extremely rough system of triangulation which appeared to have been adopted with the scaffolding, and to say how important it was that the triangulation of such structures should be carefully and systematically carried out. In several parts of the scaffolding there appeared to be quadrilateral bays without any triangulation at all. Anyone who had had much to do with scaffolding would know what a radically important point it was to have all the parts rigidly triangulated. In listening to the Author's interesting account of the designs for the new Douro bridge, and the plan of turning forward one of the temporary struts adopted in the second design to which he had alluded, he had been forcibly reminded of the fact that in so many of these large structures no advantage was taken of their great height in order to get long diagonal struts supporting the girders and reaching down to the piers. Examples of that plan were to be found in the beautiful viaducts of Mr. Brunel on the Cornwall railway, where there was a system of fan-like struts resting on the piers, and reducing the spans into manageable proportions. That sort of construction was peculiarly available in all cases of great height of road above the water-level; and in many of the examples exhibited, he should have thought that something of the kind might have been done with advantage.

Sir JOHN HAWKSHAW, Past-President, said it might be taken almost as an axiom that those who designed bridges should have reference to the mode in which they proposed to erect them. The Author appeared to think that in some cases that had not been done with sufficient care; and that was possible. Engineers were perhaps not always as careful as they ought to be in such matters; but he thought that every engineer worthy of the name did consider the mode which he thought would be necessary or best for the erection of a bridge which he had designed. The various methods of erection illustrated in the Paper were very numerous, and it was quite impossible for anybody to stereotype any special mode. Each mode must depend upon situation and upon other circumstances which had to be considered at the time; nevertheless it was always useful to those engaged in such matters to have laid before them the methods that had been successfully adopted in different places. As to what was possible, he would be a bold man who would undertake to say what was or what was not possible. For instance the Author appeared to think that the system of rolling over was applicable only to continuous girders. On that subject he should say that, if it were the best thing or a proper thing to be done, he knew of no girder that might not be rolled across the place which it was intended to span. If it were a single girder, it might be necessary to make a temporary tail-piece, and a temporary provision for strengthening the girder during the time in which it had to act as a cantilever. That was practicable where it was a proper thing to do: though of course it might be an expensive method for a single girder crossing a single opening. If a number of single girders had to be rolled forward, the work could be done in the way described; so that it was not right to say that the rolling process applied only to continuous girders. Whether the process of rolling should be adopted, or of floating, or of erecting upon a stage, each case would have to be decided for itself and by itself. All therefore that could be derived from descriptive papers was the advantage (a very important one) of having cases brought forward, in which the different methods in question had been successfully applied. Latterly bridges had been extended to a degree far surpassing the notions of old engineers. When he was in the United States some time ago, American engineers were talking of girders of 800-feet span; they seemed to think there was no difficulty in constructing them, and in that view he was disposed to agree. He therefore fell back upon the proverb, "It is no use prophesying unless you know." Some years ago it was gravely considered in this country

Sir John Hawkshaw.

n Hawk- whether a suspension bridge of 1,500-feet span could be built; and shortly afterwards, while the subject was under consideration, the work was being done in the United States. He had lately seen the bridge, which was very nearly completed. Such questions were interesting; and he thought the members were much indebted to the Author for the trouble he had taken in bringing so much information before them.

yrig. Mr. SEYRIG, in reply, said that Mr. Martineau had alluded to one of the designs for the new Douro bridge (his own) being a complete arch, joined to two side arches at either end of the bridge. He remembered that that design had struck him as being perhaps the most easy mode of erection; but it was also the most costly, the tender being about three times the amount for which the present Douro bridge had been made. The tender for the present Douro bridge was about 960,000 francs, and that for the design in question about 3,000,000 francs. He thought that one of the reasons for so great a difference in price must have been a large quantity of metal introduced merely for the purposes of erection. Mr. Lloyd had referred to a bridge which was riveted complete at a railway terminus before being run into its place on wagons. Unfortunately the railway was not always in existence before the bridges were built; and the plan referred to by Mr. Lloyd, admirable as it might be for small bridges on certain occasions, could not often be adopted. He regretted with Mr. Wawn that more examples had not been taken from this country; but he had not sufficient materials at his disposal. He might be permitted however to express a desire that the Paper should be supplemented by Mr. Wawn or some other member, so as to bring before their continental friends some of the most striking examples of English bridges. With regard to the strain at Königswart bridge, he should not have admitted such a strain for a permanent bridge; but he thought it was allowable, notwithstanding the accidental strains that might occur, to admit so high a strain for metal which was only to serve for a few months, and was not exposed to continuous vibration. The high strain was admitted by the Germans, who were perhaps bolder than French or English engineers; but it should be remembered that their calculations were made with the greatest care and nicety, and that they adhered very closely to the practice of deducting for rivet-holes. He did not know how far this was customary in England, but in France it was not done at all; any rate, the government regulations did not require it, whatever engineers might do in practice. Perhaps he had gone a little too far in saying that a continuous girder was necessary for rollin

ver. He had himself rolled girders which were not continuous: Mr. Seyrig.
here for instance there was only one span, and a temporary staging had been erected in the river a third or half-way. He ad selected examples specially to illustrate the theory, and not he modes in which different plans might be combined. The two ethods of rolling over and floating bodily might no doubt, as ad been observed, merge into each other, so that a bridge might e half rolled and half floated. This also had given him very ood results. It required, however, greater precautions, quieter ater, and greater expedition than either floating or rolling lone. Mr. Matheson had remarked that the longest overhang as that of the Kentucky bridge, 196 feet. That bridge however as not pushed forward. One of the viaducts on the Orleans railway, the Sioule, had about the same length of overhang, namely, 190 feet. In that case, for the first time to his knowledge, no additional staging was used with the ties that were till then commonly employed. Nearly all the bridges rolled over up to that time had been supplied with a gantry and chains or ropes, on the principle of the wooden stage of the Regoa bridge. The fore end of the bridge was connected with its hinder end by chains or ropes going over a temporary trestle. One of these, erected on the Orleans line, very nearly came down, owing to one of the ropes breaking. It was difficult to estimate exactly, in all the different positions which a bridge took during rolling, what would be the strains on the ropes. When the bridge had nearly reached the opposite pier, one of the ropes broke; the girder turned a little on one side, but happily nothing further occurred. After the accident, the Sioule viaduct of the same design having to be erected, the company's chief engineer proposed to do away with the ropes altogether, and the plan was most heartily adopted, because it gave much greater security. A little more metal was put into the booms, and a little more into the diagonals, and that addition remained afterwards to strengthen the bridge itself. That was also the occasion on which the set of four combined ollers (Fig. 14) was used for the first time. The largest span rossed by rolling the girder without staging or ropes was, to the est of his knowledge, one he had himself designed and erected ear Tours, over the Cher, which had two spans of 202 feet each. any bridges had been rolled over in France, where that was the neral practice, without an accident. One accident however had curred, with serious results. It was in the case of a two-span idge. On arriving near the abutment, it toppled over; that wever was not the fault of the mode of erection, but arose from

Seyrig. an error in the calculations. Rolling over certainly required more minute calculations and more care than erection on staging, but it possessed many decided advantages, especially that of economy. It had been stated that no one knew what was the condition of the booms after rolling, especially the lower booms; and the occurrence on the Tagus (Portugal) had been referred to by Mr. Reeves. Some overstraining might have been very near occurring when the bridge got over the sixth or seventh support, so that a temporary staging had to be erected. In a bridge of ten spans which he had built, with middle spans of 192 feet, there was some difficulty on coming to the tenth span. The lower boom had to be strengthened a little, but the last span was safely got over and the injury was really very slight indeed. He therefore contended that with proper precautions, even with so large a number of spans as ten, the rolling over might be accomplished with safety. As to the cost of erection by building out, it would be difficult to give a precise figure. He might say, however, that the total cost was not so much as might be supposed. In a bridge similar to the Douro, about to be erected in France, the span being 15 feet larger, but considerably higher, the government engineers had consented to pay for the erection of the large central span £12 a ton more than for the erection of the side spans. He thought the estimate for erecting bridges of that sort should be considerably lower. He made that statement from the result of the last tenders for the second Douro bridge, the total cost of the iron in a bridge like that being only about £22 per ton. The tenders varied from £21 to £24. Mr. Maynard had referred to the Crumlin viaduct, the girders of which were lifted by means of crabs and pulley blocks. The cost of that lifting was in Mr. Seyrig's opinion extremely low. Mr. Maynard added that the viaduct would have had to be 50 per cent. heavier had it been rolled over, on account of the additional quantity of iron that would have been necessary. Mr. Seyrig was not of that opinion. He had often designed bridges on different systems, and had had occasion to compare different kinds of continuous girders with others, and he believed that continuous-girder bridges could be made much lighter than single-span bridges, and that the additional metal necessary to carry them over with safety would not equal the difference between the weight of continuous spans and single spans. By properly combining the depth of the girder and the arrangement of the diagonals, more economy could be obtained by using continuous spans. In his opinion the objection to them lay in another direction—the unknown strains coming upon the girders

on account of possible variation in the level of the supports. Mr. Seyrig.
The Crumlin viaduct, he believed, was originally built with pins; and certainly the cost of erecting bridges on the American system with pins was much lower than that of riveted work. That, he thought, was the only advantage of the American bridge system as compared with the European systems; and he should willingly adopt it in cases where the difficulties of erection were very great. Africa had been spoken of as a country where it was possible bridges might have to be erected, and he hoped they might be. Labour would be very dear, and perhaps the climate might render it necessary to remain on the spot the least possible time. In such cases bridges with pin connections might be the best to adopt, so as to get the advantage of the lowest cost of erection; but only in such cases would he adopt that system. In the case of the Stadlau bridge he had given the cost of labour in rolling over, but he could not get at the cost of the tackle. The tackle might serve many times over when once a firm adopted the system of continuous girders for rolling over or lifting bridges. The tackle made more than twelve years ago for the Sioule viaduct, above referred to, had hardly ever stood idle since then. Mr. Maynard had said that his Italian work was cheaper than that of the Znaïm viaduct; but it was necessary to take everything into account. Timber was not dear in Austria, and carpenters' work, especially of the kind employed at the Znaïm viaduct, was very cheap. The connections between the different timbers were made on the Austrian system, with cramps driven into the wood, instead of bolting the pieces together; and he ventured to think the staging of the Znaïm viaduct was one of the most economical that could be made. Attention had been called by Mr. Dixon to the light appearance of French as compared with English structures. That observation was perfectly just; but the Author believed that the difference was often the result of their proportions, more than of their absolute lightness. Where an Englishman would often prefer an appearance of massiveness or solidity, a Frenchman might lay more stress on proportions that gave a light and elegant character. But engineering works, and more especially iron bridges, were not mere architectural structures; they had to undergo the tests of calculation in every one of their details, even the smallest. The closer observation of theory, and the dislike of anything that resembled rule of thumb, had certainly been the principal causes why French engineers had attained that lightness in their designs. The viaducts on the Orleans railway, mentioned by Mr. Dixon, had already

yrig. been spoken of, more especially the Sioule viaduct. The Autho could not quite agree with him as to the constant bad effects o rolling, but rather believed that only from sheer neglect of th necessary precautions had the iron been permanently injured i any such cases. Mr. Phipps had spoken of the Cawnpore bridg where the rollers had been each supported by hydraulic pressur so as never to bear more weight than their share. That pl seemed at first very simple and effective; but the Author h heard of occasions where it had again been tried with but ve indifferent results. At all events it was expensive, and he thoug no more effective than the simple contrivance shown in Plate Fig. 14. He had not spoken of suspension bridges, these bei happily considered in Europe as things that ought to be avoid Replying to Mr. J. Wolfe Barry, the Author thought the spans of t Königswart viaduct were well proportioned. A rule which oug not to be considered as absolute, but which in many cases gave once the most economical proportion of the spans for a bridge, v to make the spans nearly equal to the height of the piers. In oth words the openings between the piers, ground, and roadway, oug to be nearly square. According to this rule the subdivision of t total length of the Königswart bridge into three large openi appeared justified. They were all three made equal for the s of simplicity in the ironwork. The same rule was nearly ap cable to the Znaïm viaduct; but there, the girders being c tinuous, it was natural that the middle spans should be abou quarter larger than the side spans. As to the triangulation the scaffolding of that viaduct, it was an instance of the bold which Austrian engineers would exceptionally venture upon. must be remembered that the piers themselves served effectu in steadying the scaffolding, and that in Plate 8, Fig. 2, transverse triangulation could not be shown. It was how somewhat of a similar description to that existing lengthw Sir John Hawkshaw had gone rather further than the Autho saying that he knew of no girder which might not be rolled a the space it was intended to span. Surely that could not a to certain classes of girders, such as semi-parabolic girders o prevalent Dutch system (Plate 8, Figs. 3 and 4, for example to any system with flat tie-bars for the lower booms. In erec girders the motto ought to be: first, safety; next, cheap third, rapidity. Special cases might change the order of aims and their value; but such cases would be exceptions. best mode of erection would result from the happy combinati the three, including, if possible, a fourth—elegance of me

Reverting to the first words of his Paper, the Author believed that progress lay in this direction, namely, the right and proper combination of the design with the most judicious mode of carrying out the work, having in view not only the excellence of the permanent structure, but also the art of getting it into place. The Author wished to express his thanks to Mr. Alfred Bache, who kindly consented to translate his Paper, and to whose lucid and careful English wording of foreign expressions a great part of its interest and worth to English readers was due. He begged in conclusion to thank the members of the Institution for their kind reception of his Paper, and he could only wish that it had been more worthy of the Institution. Mr. Seyrig.

Correspondence.

Mr. Alfred Bache, referring to the observations made both in the Paper and in the discussion, with respect to the risk of girders being permanently injured by the strains in rolling them over their spans, remembered an instance of a girder bridge carrying one railway obliquely over another, where the extent of overhang and consequent strain upon the girders had been diminished by pushing them across at right angles to the lower line, and then slewing them round afterwards into the oblique direction of the upper line. That expedient depended however upon having sufficient clear space in the rear of the abutment for manœuvring the girders at the level of the upper line. Mr. Bache.

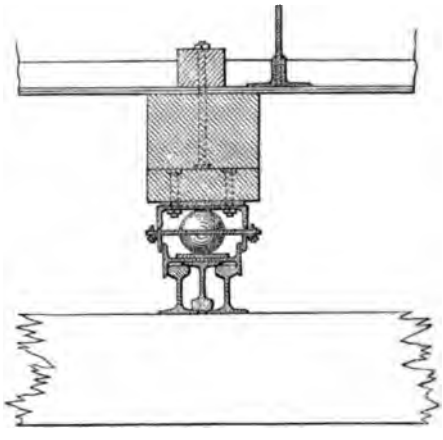
From the drawings shown of the rollers, it was evident that, where these were used, the lateral guiding and steadying of the girders had to be provided for by some other means. But in the ball apparatus of Herr Weickum[1] (Fig. 6, p. 202) it would be seen that the lateral guiding was effected by light angle-irons riveted along the top and bottom of each side of the live plate. The H iron, forming the trough in which the balls ran, was carried on ordinary flat-footed rails; a pair of these were spiked down alongside each other, whilst a third rail inverted was placed between them; the three, together with the H iron, made a very firm path for the load to travel along. The balls were $4\frac{5}{8}$ inches in diameter, running loosely in circular holes in the flat live plate.

The extensive replacing of timber bridges on Hungarian and Austrian lines, referred to in the Paper, had its counterpart in this

[1] *Vide* Mémoires de la Société des Ingénieurs Civils, 1880. "Note sur quelques cas spéciaux de montage des ponts métalliques," par T. Seyrig.

Bache. country at the present time on the Cornwall railway, where stone viaducts were now in progress of construction for replacing the original timber viaducts, which were themselves being made use of, he believed, as scaffolding for the erection of the stonework. It would be interesting to know the methods adopted for turning the stone arches when the top of the piers was reached, and for completing the transference of the permanent way from the old timber

FIG. 6.



work to the stone structure with the least interruption of traffic. On the completion of these extensive works he trusted some particulars of them would be furnished to the Institution by the engineer of the railway.

In the Douro bridge it appeared to him that the varying width of the arch in plan, tapering from about 50 feet at the springing to only 13 feet at the crown, would cause the joints of some of the component bars, such as the diagonal struts and ties, to come together not properly flat. It had not been stated whether the work was put together by riveting, or pin-connected by bolts: though from the character of the structure the latter seemed presumably the method. In either case he should be glad to know how the ends of the several bars were all got truly square to the bolts or rivets: were they each bent accurately beforehand to the small extent requisite? Also were guy ropes employed for steadying the arch laterally during erection; or was its tapering width alone relied upon? The accuracy of erection, whereby the meeting ends came together at the crown without material deviation laterally in such a length of span, suggested the enquiry for

some information respecting both these points. Would the Author kindly mention also what length of time had been occupied in the erection of the entire bridge, and of the central arch; and during what seasons the work had been carried on, and whether any serious storms had been encountered during its progress? Mr. Bache.

Mr. Wilfred Bailey observed, in reference to the floating staging used upon the Niagara "International" bridge at Buffalo, that, as Assistant-Engineer of the bridge during its construction, he could testify to the complete success of the plan referred to, and to its great convenience in that particular case. The staging had been fully described and illustrated in Mr. Gzowski's work on the "International Bridge," a copy of which was in the library of the Institution. He exhibited a photograph, taken by himself, showing the staging in position for a 248-feet span, with portions of the ironwork in progress of erection. The six pontoons shown were connected by chain cables to a small pontoon securely anchored some distance up stream. On the completion of the erection of the ironwork, the staging was adjusted so that the ends of the girder were immediately over their destined positions on the piers, and the structure was then gradually lowered by admitting water into the pontoons, until it rested upon bedplates previously fixed in position. After this the admission of water was continued until the lower staging, which together with the pontoons formed an independent structure, was free from the upper scaffolding, which remained hanging to the ironwork until taken down for use in the next span. The whole lower system was then, by means of steam-tugs attached to the small pontoon, drawn from under the girder, and towed into position for receiving another span. In this manner the staging was utilized for five spans in succession. The operation of transferring the staging bodily from one span to another as described, required, according to length of span and velocity of current (the latter being about 6 miles per hour in the middle of the river), the assistance of from four to seven steam-tugs, which could easily be hired in the vicinity, whereby the economy of the system was greatly increased in this instance. Under different circumstances it might be preferable to disconnect the various parts of the staging, and to re-erect it after towing the pontoons separately into the new position. Mr. Bailey.

Mr. Benjamin Baker thought Mr. Seyrig had done his work so thoroughly as to leave little but gleanings for those joining in the discussion; nevertheless a few additions and corrections might perhaps be made. In the section dealing with "Erection upon Staging" it was stated that the Kuilenburg bridge of 492 feet Mr. Baker.

ker. clear opening was the largest in existence with horizontal g
but this was not strictly true, as the main-trussed girders
Cincinnati Southern railroad bridge were 515 feet in span,
the Poughkeepsie bridge, across the Hudson, now nearly co
had five spans of 525 feet each from centre to centre of th
The system of erection with the aid of flexible suspensior
was condemned by Mr. Seyrig as inconvenient; but this o
was true only in a restricted sense, as, so far from being incon
the system was so convenient that all the longest span bri
the world had been so erected. The East River bridge, 1,60(
clear span, with its heavy steel cables and deep stiffening
and platform, was being erected solely by the aid of flexil
ropes; and the existing railway bridge at Niagara, an
other large bridges in America, had been so erected. Wh
single telegraph wire could be got across a river or gorg
could a stiff and strong suspension bridge be erected; for a
of wires brought together as parallel fibres and wrapped w
constituted the ordinary cable of an American suspension
and experience had shown that, notwithstanding the fl
complained of by Mr. Seyrig, the heaviest stiffening girde
be, and were, erected by the aid of these cables without
convenience whatever. In the section on "Erection by flo
girders bodily," it was observed that the mode of erection
for the Britannia bridge was "not long in being imitat
where, either wholly or in part." It might have been ad
the former mode of erection was in itself "imitated in par
the system adopted by Telford a quarter of a century befo
neighbouring Menai suspension bridge. Stephenson floate
feet length of tube on pontoons into position between t
and lifted it about 100 feet high by hydraulic power in a
whilst Telford floated a 450-feet length of main chains on
wide raft into position between the piers, and lifted it al
feet high by manual power in a couple of hours. One of t
recent and important examples of erection by lifting bo
that of the bridge across the Volga at Syzran, which i
thirteen spans of 363 feet each. The girders were built on a
and floated off by seven pontoons carrying a forest of tim
folding of the requisite height to deposit the girders at or
the piers. With the girders upon the top of the staging
height of the top-heavy mass was no less than 120 feet. Th
were 154 feet long by 28 feet beam, and the weight of
span was about 520 tons. When the immense surface expos
wind, the rapidity of the current, the great floods, upwar

eight, and other conditions were taken into consideration, Mr. Baker.
be conceded that this was one of the boldest examples of
by floating bodily. Many bridges in Russia had been
ito position, the earliest example being perhaps the bridge
e Niémen at Kowno, constructed by Messrs. Gouin in 1862.
able difficulties were encountered in carrying out the ope-
and the contractors found it expedient to float but two out
our girders constituting the bridge, and to adopt other
f erection for the remainder. The Tay bridge was another
ng example of erection by floating both piers and super-
s. Two pontoons carried the 245-feet spans which were
place, not by previous erection on a lofty staging as in
a bridge, but by a modification of the Britannia-bridge
of lifting by hydraulic rams. Mr. Seyrig justly observed
arge plant in the shape of pontoons, &c., was required for
ridges bodily. It must have occurred to many that a
bridge with its cross-girders and floor was in itself a big
omed pontoon without sides. Thus a double-line 250-feet
lway bridge could be at once converted into a pontoon by
; up the lattice sides 3 or 4 feet high with 1½-inch planking,
e effective draught of water required to float the weight
ily be about 2 feet 3 inches. Complete spans thus simply
d into barges might be built on shore and launched sideways,
the 260-feet girders of the Niémen bridge; and might be
ndreds of miles if necessary down the river to the site
ridge, where they might be moored below their respective
til a convenient moment arrived for swinging them into
Even in an exceptionally fast current the lateral pressure
ontoon would be less than that of a very moderate wind
a mass of scaffolding as that of the Volga bridge. The
dge builders had similarly made their timber caissons self-
ig by putting in a temporary bottom before they floated
to place. In the section on "Erection by pushing and
ver of girders," Mr. Seyrig stated that the system was only
le to "bridges of the continuous-girder class, comprising
two spans." He must have forgotten for the moment one
st recent and interesting examples of this mode of erection,
bridge across the Rance near Dinan in Brittany. The main
15 feet long, 39 feet deep at the centre and 25 feet deep
d, with a cambered upper flange, were erected by adding
ily to the front end of the girder a length of about 200 feet
r-work prepared for another viaduct on the line, counter-
g the rear-end of the girder, and rolling across in the usual

Baker. way. In the section on "Erection by building out," it was remarked that the first instance of a bridge erected on this principle was that of El Cinca in Spain, having a single arch of 230-feet span. It might be remarked in passing that in Vol. I. of the Minutes of Proceedings would be found the following passage under date February 13th, 1838: "Mr. Brunel exhibited a model illustrative of his method of constructing an arch of large span without centering;" and there were many other evidences of the fact that this system had always been favourably entertained by engineers. Indeed it could be shown beyond all doubt that bridges were erected by building out at least two centuries antecedent to the El Cinca bridge. Turner, in the history of his Embassy to Thibet, illustrated and described an ancient bridge on the cantilever and central-girder system which had been so erected. The cantilevers consisted of four rows of superimposed timbers, the lower ones projecting about 10 feet from the abutment, and the others projecting successively to further distances of 10 feet, until the cantilevers each overhung 40 feet from their respective abutments, leaving an intermediate gap of 32 feet which was bridged by sliding timbers across, and so completing the whole span of 112 feet. Again, in 1810, a Mr. Pope proposed to construct a cantilever bridge of 1,800-feet span across the East river, of which a model cantilever, 50 feet in length, was exhibited to the New York public with a test load of 10 tons suspended from its end. This bridge was to be erected by building out; and if Mr. Seyrig were called upon to put into immortal verse the last few pages of his Paper descriptive of his proceedings at the Douro bridge, he could perhaps hardly do better than appropriate bodily Mr. Pope's lyrical version of his intended operations at the East river, of which the following was a sample:—

> "Each semi-arc is built from off the top,
> Without the help of scaffold, pier, or prop;
> By skids and cranes each part is lowered down,
> And on the timber's end grain rests so sound.
> Sure all the bridges that were ever built,
> Reposed their weight on centre, pier, or stilt;
> Not so the Bridge the Author has to boast;
> His plan is sure to save such needless cost.
> A ladder on each side is lowered down,
> And shifted from the fulcrum to the crown," &c.

English engineers had erected very few bridges by building out, and therefore reference should not be omitted to the railway bridge over the river Dal in Sweden, built and erected by Mr. Hutchinson of Darlington. This bridge had a centre span of 208 feet, and

wo side spans of 80 feet, which were united temporarily to the main span by channel-iron ties of sufficient strength to sustain the all of the overhanging half of the main span, weighing 80 tons uring erection, and acting with an effective leverage of 57·2 feet. he counter-weight consisted of 47 tons of rails at the end of the 0-feet girders, and 18 tons near the point of attachment of the ties, disposed as not to produce an undue strain on any part of the irder. No difficulty was experienced in carrying out that work; nd Mr. Seyrig was doubtless correct in his concluding remark hat iron bridges of all kinds admitted of being erected without taging or auxiliary girders of any description. Mr. Baker.

Mr. T. CLAXTON FIDLER remarked, in connection with the method f erecting continuous-girder bridges by the process of rolling ver, that it was of importance to ascertain the extent to which he girder would be strained by its own weight during the pro-ess, and to provide for any excessive local strain by a corresponding ddition of strength in the design, or by temporary trussing. It ad been stated in the discussion that the economical advan-age of this method of erection was greatly impaired, or entirely nnulled, by the cost of the iron which must be added to the girder to make it strong enough to bear the process; and that, where this additional stiffening had not been adequately provided, instances had occurred in which the girder had been crippled by straining while being carried forward across the spans. The bending stresses which operated in different parts of the girder at each stage of its forward movement depended upon a number of varying conditions (including the relation between the lengths of the several spans), so that in detail each case must be treated individually; but it would not be difficult to estimate broadly the stress which any continuous girder would undergo in the process of being "rolled over," as compared with the stress which it was ultimately intended to carry in the completed structure. Mr. Fidler.

1. In every case the greatest strain which the girder would have to bear would occur at the moment when the leading end had been projected nearly across the widest opening, but had not yet come to rest upon the opposite pier, so that at this moment it was supporting the whole length of the span as a cantilever; and f s represented the flange-stress which the girder would undergo t the centre of the span when merely supported at each end, the mporary stress at the moment above described would be equal to ·4 s. This maximum stress would be located at the point which that particular moment was situated over the last supporting er; while the sectional area of flange which would be provided

:. Fidler. at this point, having regard only to the maximum strain i completed structure, depended upon the position which the in question would ultimately occupy in the structure.

(*a*) If the bridge consisted of a number of equal spans, the in question would ultimately coincide with the first pier i series, and here the flange would naturally have its max sectional area. If S represented the flange-stress which occur at the centre of the span if the girder were loaded wi entire permanent and rolling load, and merely supported a end, then the stress which would be provided for in the conti girder at the first pier of the series would not be less than and perhaps more, according to the intensity of the live lo the number of spans. Comparing this permanent stress wi maximum temporary stress before mentioned, it would be see no additional strain would be incurred at this point in the p of rolling over, unless the weight of the girder per lineal fo greater than one-fifth of the total weight of the bridge an load. The weight of a continuous wrought-iron girder generally only reach this proportion to the total load wh spans were about 150 feet in width; it followed that wh spans were not in excess of this width, the temporary str this point of the girder would not be greater than the perm strain which it was calculated to carry; while it was not that any great harm would result, even if the temporary were 50 per cent. higher than the permanent strain.

(*b*) If the end spans of the bridge were shorter than the and their length about $\frac{8}{10}$ of the intermediate spans, this ma temporary strain would occur at a weak point in the girde at a point which would ultimately be situated in the secon and at a distance of $\frac{1}{5}$ of the span from the first pier, whe permanent strain was much smaller; and in girders of a siderable span the flanges would require to be strengthened point.

But generally, when the end spans were shorter than the it would perhaps be advisable to make up the length by ad temporary projecting beak or cantilever to the leading end girder, in order to locate the maximum stress at the p maximum strength.

When all the spans were of equal length, this proceeding obviously be worse than useless, as its effect would be to the greatest strain upon one of the weakest points in the gi

2. It was necessary also to consider the heavy temporary which occurred at short distances on each side of the p

maximum stress; generally the two leading spans of the girder should be made strong enough at all points to bear the entire weight of the two spans balanced upon a central support. It had been shown that the sectional area of flange at the first pier was usually sufficient to carry the maximum stress with safety when the spans were not more than 150 feet; but if the girder were proportioned exclusively with regard to the permanent load, there would be a point in the flange on each side of the pier proportionately weaker, and these points would require strengthening. Mr. Fidler.

The cost of adding this extra metal in the first instance would however amount to very little when spread over the whole cost of the ironwork. If the girder was built continuously at the land end as the successive spans were pushed across, this expense would generally be confined to the two leading spans; but if the bridge was built in sections of five or six spans, and each section launched across, so that the tail-end had to be self-supporting, the same precaution must of course be observed in the last two as in the first two spans of each section. Fig. 7 represented the flange-stresses in a girder of five equal spans when being rolled over, and at six successive stages in its progress across one of the openings, as indicated in the elevation Fig. 8, the tail-end being detached from the land and being self-supporting. The maximum stresses at b and e were equal to $-4\ s$, and in the central span the greatest stresses were about $\frac{3}{4}\ s$ to $\frac{8}{10}\ s$.

3. As compared with the two leading or two trailing spans, the temporary strains in all the remaining length of the girder, however many spans it might consist of, were very small, and would not at any point exceed the above maximum of $\frac{8}{10}\ s$; but as this strain, or something like it, would occur at every point in the girder in succession, as that point passed over a pier or over the centre of an opening, it would be necessary to consider these strains in relation to the weakest points in the girder, which in some cases might not be intended to carry a greater stress than $\frac{1}{17}$ S to $\frac{1}{4}$ S.

4. It was unnecessary to discuss the shearing strains, which could easily be estimated from the diagram. In conclusion it was not difficult to see that a girder might easily be crippled in the process of rolling over, if due care was not taken in the first instance to compare the strength of the girder at every point with the temporary strains which would be located at that point; but if this precaution was taken, a very trifling amount of additional metal would be sufficient to render a continuous girder of any moderate span strong enough to be safely erected by rolling over.

ller.

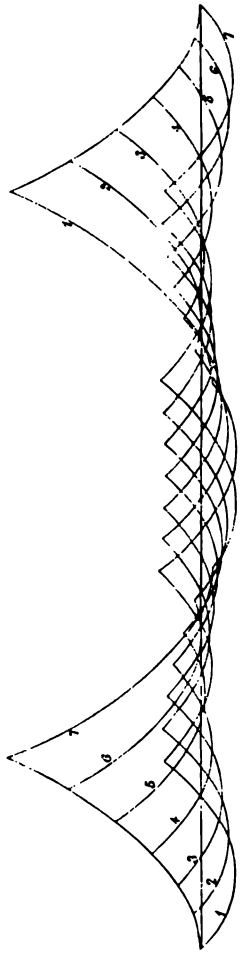


Fig. 7.

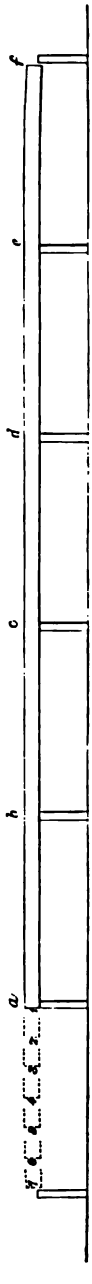


Fig. 8.

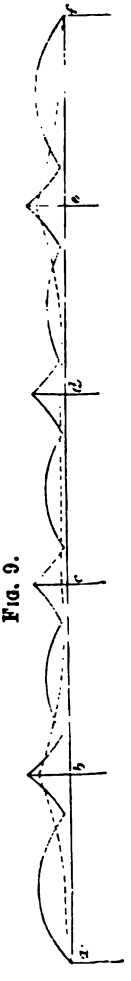


Fig. 9.

the five-span girder above illustrated, if the weight of the ler was one-fifth of the total load, the additional metal required the flanges was less than 6 per cent. (allowing a temporary in 20 per cent. greater than the permanent unit strain), while, he girder was built continuously at the land end, half this ount would suffice, and the proportion would be still smaller if re than five spans were pushed forward; but if this trifling lition were omitted, the girder would be strained to four times e intended working strain, or perhaps to an intensity of 20 tons r square inch, at certain points in the girder. Fig. 9 represented e sectional area of flange required in the five-span girder for e permanent and temporary strains on the assumptions before entioned. Mr. Fidler.

Mr. JOSEPH M. WILSON remarked that the erection of iron bridges Mr. Wilson.
n the Pennsylvania railroad had been accomplished almost univer-lly by means of staging, the heights above the water or ground ing generally not excessive, the waters of the rivers favourable this method, and the risks from freshets not very great except at rtain seasons, which could usually be avoided with a little care. he staging, or trestle-work as it was called, consisted of a series of estles, placed say 10, 12 or more feet apart, depending upon the ngth of panel of the new structure, each trestle formed of a cap ith four upright posts, all in the same plane, but inclined out-rds towards the bottom generally, like an inverted W, to brace d stiffen the trestle. The section of the timbers was about inches square, and the upright members were cut to length to it the location of the trestle, being made a little short so that y irregularities in level might be obviated by blocking up on em the cap or the longitudinal timbers which ran from cap to p and connected the various trestles together. These carried e lower members of the new truss, and upper trestles were amed on the others to carry the upper members. A supply f 2 or 3-inch plank, called running plank, and scantling timber as also necessary. Of course details might vary according to ircumstances, but that was the general arrangement. The cost f erection usually averaged about $\frac{1}{2}$ cent. per lb. of the iron n the new structure. In replacing a pivot draw-span of 192 et length, in the long bridge over the Potomac river at Wash-gton, D.C., where navigation and the requirements of the rail-ad necessitated keeping the draw in working condition almost ntinuously, the new structure was erected on boats and floated to place, the old bridge being taken out in the same way. Rail-ad travel was suspended at noon on Sunday and resumed at

Wilson. 6 A.M. next day. Navigation was stopped from 6 P.M. on Saturday, and the draw was open again for boats at 1 P.M. on Monday. The actual time occupied in floating out the old draw and putting the new one into position was forty minutes. The Pennsylvania railroad having been originally constructed almost entirely with wooden bridges, the renewal of these with iron, without causing interruption to travel, had necessarily given considerable experience in the matter. Each case had of course required special consideration; but the general method had been to place the trusses of the new structure a little to one side of the old ones, and slightly lower or higher, so that the lateral connections might be made between the new trusses without interfering with the old ones. After the new bridge had been sufficiently erected to allow running over it, the traffic was transferred on some Sunday, when the absence of freight business gave a little more time between the trains, the work being accomplished in a few hours. The old structure was then removed at leisure; and when this had been done the new bridge was moved over by means of hydraulic jacks and rollers to its true position, and the floor system, &c., was entirely completed. Bridges of 700 and 800-feet total length had been successfully erected in this manner without any interruption to traffic. The bridge over the Delaware river at Trenton was a through structure of three trusses, having five spans, the total length being about 1,000 feet. The up-stream or north side was used for highway traffic, while the south side had a double-track railway. In this case the piers and abutments were extended on the down-stream side, by temporary timber framing, so that the southern and centre trusses of the new bridge could be erected entirely independent of the old bridge. Rails were next laid, and the traffic of the railroad was transferred to the bridge in its new position. The old bridge was then removed, and the new structure, or rather that portion of it erected, being the railroad half, was moved bodily 18 feet sideways, by means of rollers and hydraulic jacks, into its destined position, uninterrupted traffic proceeding over it during the whole time. The north truss was next erected from the middle truss and close to it, without scaffolding, and was afterwards pushed into its proper position, having temporary adjustable timber stays connecting it with the middle truss, and holding it stiffly in place. The lateral connections were then put in, the floor system was laid, and the bridge completed. Of course highway traffic was interrupted during the erection, and was taken by another bridge farther up the river. It might be stated that seldom more than one or two

spans were trestled at a time, unless in special cases of great haste: so that in a long bridge the same timber might be used over and over again. Mr. Wilson.

Mr. T. WRIGHTSON described an arrangement lately designed by him, and adopted by the firm of Head, Wrightson and Co., in doubling the Meldon viaduct on the London and South-Western railway, under the supervision of Mr. W. Jacomb, M. Inst. C.E. The original single line was to be kept open for traffic, and as the valley over which the viaduct passed was deep, it was desirable to dispense with scaffolding, which would have been very costly. The new line was to be supported on pairs of lattice girders, resting on wrought-iron built piles, clusters of which were placed at 90 feet distance from centre to centre. These clusters were erected from the bottom, the pieces being lifted into position by means of a swinging derrick, supported on a platform attached to the old structure at the top. The method of erecting the main girders was as follows:—The girders were put together on the embankment at one end, and were laid parallel to, and a few feet from, a siding of the existing railway. Two powerful bogie cranes were specially constructed, each capable of lifting half the weight of one girder. When the cessation of traffic allowed the erection of a girder to be effected, one of these cranes was run to each end of the girder, and by means of powerful gearing the girder was raised a few inches from its supports. A locomotive was then attached to the foremost crane, and pulled the two cranes with their suspended girder out of the siding into the main line, the centre line of the girder being always parallel to, but several feet clear of, the rails on which the cranes were moving. In this way the suspended girder was carried over the viaduct, and as soon as it came over the clusters of columns which it had permanently to span, it was lowered by the gearing. The cranes were made with a heavy balance weight at the opposite side to the girder, so as to prevent the crane tipping. When the girder was landed, and before the suspending chains were taken off, the balance-weight was moved inwards so as to keep the centre of gravity well within the base of the rails. This being done, the chains were released and the cranes pushed back for another girder. The whole arrangement worked well, and the six spans, with all cross-girders and top work, including piers and clusters of piles, were erected in sixteen weeks. The time occupied in moving out and fixing a girder weighing 1 tons being about two and a half hours, no cessation of the traffic was at any time necessary. This method of erecting was of course only available in the case of an already existing line being within Mr. Wrightson

rightson. a reasonable distance alongside. When once the cranes, which we somewhat costly, were made, the cost of erection was very sma and the work might be done with great rapidity.

yrig. Mr. SEYRIG, in reply to the correspondence on the Paper, marked that the difficulties mentioned by Mr. Bache in relation the Douro bridge were easily got over. The two girders whi formed the large arch were each contained in a plane, these t planes leaning towards each other and intersecting in a li parallel to the roadway, about 210 feet above springing lev There was no more difficulty in making them and in buildi them up than in constructing an ordinary arch. The only di culty resulting from the form adopted was in the joints of cross-bracing with the booms, the angles of which varied fr panel to panel. Great care however was taken, and no er occurred, which otherwise might have led to great delay. work was riveted throughout, the only thing resembling a being the knee-joint where the arch rested on its abutments. guy ropes were necessary for steadying during erection, the ov hanging arches forming as it were a jib with a base of ab 50 feet. As mentioned in the Paper the erection of the s occupied from March till August 1877, and the bridge was ope in the following November. The Douro valley in this part often swept by high winds, and during the period of overhan the bridge several very severe storms were experienced; but t had no injurious effect whatever on the structure.

It had been remarked by Mr. B. Baker that all the bridge largest span in the world had been erected by the aid of flex suspension chains. The Author had not spoken of those structu they formed a class so distinctly separate that they could ha be comprehended under the common name of iron bridges. cables used in erection were generally part of the structure it What he objected to was the use of ropes as chains for tempo purposes, and for supporting rigid structures, made up by rivet or by pins. Any scaffolding erected on chains would probabl so flexible as to prevent the coming together of parts made great nicety, and would give much trouble in bringing them their proper places and connections. Such had been the cas El Kantara, where the chains had been used only as the prin support of a wooden arch. There might be something attra in the idea that a railway bridge with its cross girders wa itself the skeleton of a flat-bottomed pontoon; but lattice gir had now superseded plate girders, and the closing up of thes the sides and bottom with watertight planking would prob

involve an outlay far greater than any other method. This was no doubt the reason for not continuing the erection by floating of the girders of the Niémen bridge. Moreover the practice might be dangerous, for a single weak point in the temporary planking would cause the girder to sink. No comparison could be made between the floating of a timber caisson and an iron bridge. The example of the bridge over the Rance was an exception which confirmed the general rule that rolling over was applicable to bridges of at least two spans. Had it not happened that another bridge, intended to be erected not far away, was capable of being so proportioned in width and in height as to join the principal viaduct, the Dinan bridge could not have been erected by rolling over. Some other better and cheaper method might have been devised, rather than building a temporary projecting part to enable the rolling process to be adopted. To double the length of a bridge for the sake of erection was an unscientific method; nor would it have been resorted to in this case but for the exceptional facilities afforded by another similar work near at hand. It certainly was interesting to learn that the Thibetans had been so far advanced in the process of erection by overhang; but as to Mr. Brunel's model, and Mr. Pope's poetical proposition, they were, as Mr. Baker had said, only "intended operations." Mr. Seyrig.

He thought himself fortunate in having elicited Mr. Claxton Fidler's remarks on the stresses occurring in girders while rolling over. They agreed entirely with the results of his own practice. Mr. Fidler had established the fact, which appeared to be doubtful to some, that a very small amount of additional metal would suffice to strengthen any well-proportioned girder for the purpose of rolling over. It would be important, however, to consider the conditions of local flexure which might take place in the lower booms while passing over the rollers. Plate girders would generally present neither danger nor difficulty, but lattice girders might do so, especially with large panels. If the lower boom were of a ⊥ section or of a box section, the upper edge of the vertical plates might be strained to considerably more than the breaking strain, not being intended when in their ultimate position to sustain any other than a longitudinal stress. In calculating this compound stress, due to flexure and compression, it would be well to allow a wide margin for safety. Again, the lattice bars might present points of danger. In the middle of the spans they were often of very slight dimensions, and made of flat tie-bars unable to resist compressive strains. As the girders went over the different piers, the direction of the strain must change several times; and this

eyrig. required close investigation. It was easily seen that if, for example, the whole girder rested on the piers at those points which were ultimately to be in the middle of the spans, the weakest lattice bars of all would have to support the total weight. The one great danger in rolling over was not the highest strain to which some pieces might be subjected, but the crippling or bending of parts which, when once they had deviated from their straight form, no longer afforded any security.

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14 December, 1880.

WILLIAM HENRY BARLOW, F.R.S., President,
in the Chair.

The discussion upon Mr. Seyrig's Paper on "The different modes of Erecting Iron Bridges" occupied the whole evening.

Correspondence on Explosive Agents.

A communication has been received from Mr. R. M. GARDINER, Managing Director of the Cotton Powder Company, in reference to a statement made by Mr. Henry Hall, one of H.M. Inspectors of Mines, and published in the "Minutes of Proceedings," vol. lxi., p. 130. In alluding to tonite, Mr. Hall remarked that "one instance had come under his personal observation, where the fumes proved fatal to life in sinking a pit." On being asked to name the instance, Mr. Hall replied that the case he had in his mind occurred at the Lynne pit of the Haydock colliery, St. Helens. Mr. Gardiner wishes it to be known that the case in question dates as far back as October 1876, and that a coroner's jury, after a searching investigation into all the circumstances, returned a verdict, "That death resulted from congestion of the lungs, but whether it was due to natural or exciting causes, there was no evidence to show." Mr. Gardiner also states that the use of tonite in the works at the Haydock collieries has been continued up to the present, and that neither there nor in any other locality before or since has there been any such effects as those assumed. Mr. Gardiner.

ANNUAL GENERAL MEETING.

21 December 1880.

WILLIAM HENRY BARLOW, F.R.S., President, in the Chair.

THE notice convening the meeting having been read,

Messrs. A. T. Atchison, J. D. Baldry, R. W. P. Birch, C. Fr C. E. Hollingsworth, R. C. May, T. M. Smith, J. Tho and A. Williams were requested to act as Scrutineers o Ballot for the election of the President, Vice-Presidents, and Members of Council for the ensuing year; and it was re that the Ballot Papers should be sent for examination at int during the time the Ballot remained open.

The Ballot having been declared open, the Secretary rea Annual Report of the Council, on the Proceedings of the tution during the past year. (*Vide* page 220.)

Resolved,—That the Report of the Council be receive approved, and that it be printed in the "Minutes of Proceed in the usual manner.

The Telford and Watt Medals, the Telford and Manby Pren and the Miller Scholarship and Prizes, which had been aw were presented. (*Vide* pages 236 and 237.)

Resolved,—That the thanks of the Institution are justl and are presented to the Vice-Presidents and other Memb Council, for their co-operation with the President, thei stant attendance at the Meetings, and their zeal on behalf Institution.

Mr. Abernethy, Vice-President, returned thanks.

Resolved unanimously,—That the cordial thanks of the M be given to Mr. Barlow, President, for his perseverin deavours in the interests of the Institution, for his unren attention to the duties of his office, and for the urbanity he all times displayed in the Chair.

Mr. Barlow, President, returned thanks.

Resolved,—That the thanks of the Institution are due, a presented to Messrs. W. B. Lewis and Charles Douglas F the comprehensive statement of Receipts and Payments the

prepared; and that Messrs. Charles Douglas Fox and Edward Easton be requested to act as Auditors for the ensuing year.

Mr. W. B. Lewis returned thanks.

Resolved,—That the cordial thanks of the Institution be tendered to Mr. Charles Manby, Honorary Secretary, and to Mr. James Forrest, the Secretary, for their long-continued and valued services.

Mr. Forrest returned thanks.

The Scrutineers then announced that the following gentlemen had been duly elected:

President.

JAMES ABERNETHY, F.R.S.E.

Vice-Presidents.

Sir W. G. Armstrong, C.B., F.R.S.	Fred. Jos. Bramwell, F.R.S.
Sir Joseph Wm. Bazalgette, C.B.	James Brunlees, F.R.S.E.

Other Members of Council.

George Berkley.	William Pole, F.R.SS. L. & E.
George Barclay Bruce.	Robert Rawlinson, C.B.
Sir John Coode.	Alexander Meadows Rendel, M.A.
Edward Alfred Cowper.	Charles William Siemens, F.R.S.
Alfred Giles.	David Stevenson, F.R.S.E.
Sir Charles A. Hartley, F.R.S.E.	Sir W. Thomson, F.R.SS. L. & E.
Harrison Hayter.	Sir Jos. Whitworth, Bart., F.R.S.

Edward Woods.

Resolved,—That the thanks of the Meeting be given to Messrs. Atchison, Baldry, Birch, Frewer, Hollingsworth, May, Smith, Thomson, and Williams, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office; and that the Ballot Papers be destroyed.

ANNUAL REPORT.

At the last Annual General Meeting a question was asked as to whether it was compulsory upon every member to vote for the full number of persons required to constitute the Council, or if, to put an extreme case, a balloting list containing only one name would be valid. In reply the then President, Mr. Bateman, stated that, as the by-law, sect. v., cl. 3, provided only that the number remaining on the list should not exceed the number to be elected to each respective office, this had always been interpreted to mean that a list would be valid with a less number, and instructions to this effect had invariably been given to the Scrutineers. As it seemed desirable that any doubt which might exist should be settled by legal advice, Counsels' opinion has since been taken on the subject and is entirely confirmatory of the view expressed by Mr. Bateman. At the same time Counsel have pointed to the possibility of a full Council not being elected, and to the inconvenience that might thereby ensue. But, apart from this possible source of inconvenience, the Council are of opinion that, in so grave and important a matter as the election of the governing body, the interests of the Institution render it incumbent on each voter to record his judgment in respect of the whole number of Council to be returned.

In the balloting list for this election some slight modification have been made, by the omission, after "President," "Vice-Presidents," and "Other Members of Council," of the words "One name to be returned," "Four names to be returned," and "Fifteen names to be returned," respectively, as those words might be considered to render it obligatory upon the members to vote those numbers, and thus to be in conflict with the marginal note printed on every list. The by-law, based on the Charter, as to the constitution of the Council has been printed in larger type and at the head of the list, so as to draw attention more pointedly to its provisions.

When the Council were engaged in preparing a list of persons suitable for the various offices in the Council for the ensuing year as required by the by-laws, Mr. Barlow intimated that he adhered to his original intention not to allow his name to be proposed as President a second time, as he believed there was a general feeling that it would be advantageous for a President in future to hold

office for one year only, and that the former practice of the President remaining in office for two years should be discontinued. According to the by-laws the senior Vice-President in duration of office is required to be put in nomination for President, unless he gives notice in writing of his intention not to serve. Sir W. G. Armstrong, C.B., the senior Vice-President, having stated that he would be unable to devote the necessary time in the following year to the performance of the important duties attaching to the office, Mr. Abernethy, the next Vice-President in rotation, has been proposed for President. The vacancy thus caused among the Vice-Presidents has been supplied by the selection, by ballot in the Council, of Mr. Bramwell. The fourteen remaining members of Council have been retained on the list, to which ten other names have been added (several suggested for the first time), to complete the number required by the by-laws.

As the amended by-laws have now been in force two years, the Council think it advisable to refer to their operation in regard to candidates seeking election.

By the amendments enacted on the 2nd of December 1878, which were mainly directed to the separation of the professional from the non-professional Associates, it was provided that only those persons who had been regularly educated as Civil Engineers, and who were engaged in the design or the construction of works falling within the province of the Civil (i.e. *civilian*) Engineer, should be eligible for election into the Corporation, unless, indeed, the candidate had practised the profession on his own account for at least five years, and had also acquired a considerable degree of eminence in the same, when he might be recommended for ballot as a full Member. Further, the future "Associates not entitled to the privileges of Corporate Membership" were not to be Civil Engineers by profession. The Council have thought it expedient to raise the standard of this attached class, so as not unduly to increase its number, and with this object among other things to recommend for election only such persons as are distinguished in their particular walks of life. The effect of these rules is that all persons who have gained access to the profession without being regularly trained and educated for it, are, so long as they continue to occupy a subordinate position, and indeed until they have been in independent practice for at least five years, and have also attained eminence, disqualified for being received as Corporate Members, and are likewise not eligible as non-Corporate Associates, as that class is to be composed of persons of position

in some walk of life other than that of a Civil Eng
well that the foregoing facts should be borne in mi
persons not possessing the requisite qualifications
suaded from making application for admission, whi
in disappointment.

Notwithstanding these limitations, the increase in
composing the Institution, without reckoning the S
been at the rate of upwards of 4 per cent. during the
months—a rate, however, that must have been frequen
as may be inferred from the fact that the numbers on
are double what they were between eleven and twel
The elections last session comprised 2 Honorary Memb
bers, 129 Associate Members, and 16 Associates
restored to the list); together, 190. On the other han
tions, from deaths, resignations, and erasures from
have been 68, leaving an effective increase of 122, a
present aggregate of 3,082. The details are given in
Table.[1]

The additions to the roll of Honorary Membe
Ferdinand de Lesseps, G.C.S.I., and Professor T

[1] The following Table shows the changes that have occurred
classes belonging to the Institution, irrespective of the Students,
two Sessions:

—	Session 1878–79.					Session		
	Honorary Members.	Members.	Associate Members.	Associates.	Totals.	Honorary Members.	Members.	Associate Members.
Numbers on Nov. 30, 1878 and 1879 .	16	1,061	..	1,738	2,815	17	1,140	1,2
Transferred to Members.	..	..	..	68		..	..	4
Ditto to Associate Members . . .	..	..	..	1,080		..	..	..
Elections. .	1	40	152	23	216	2	43	1
Restored to Register .	..	..	..	..		..	..	..
Deaths . .	..	18	3	10		1	15	
Resignations.	..	4	3	15	−71	..	5	
Erased . .	..	7	5	6	145	..	..	
Numbers on Nov. 30, 1879 and 1880 .	17	1,140	1,221	582	2,960	18	1,209	1,2

recognition by the Institution of the benefits conferred by the former, in respect of the Suez Canal, may perhaps be deemed somewhat tardy; but it should be explained that of late years very few such elections have taken place, as it seemed to be considered that this class should be limited to a small number. It will be within the recollection of many now present that Sir Ferdinand de Lesseps acknowledged personally the gratification he felt at his election; while Dr. Tyndall has intimated that he ranks the recognition accorded to him by the Civil Engineering profession as among the highest honours ever bestowed upon him.

The deaths recorded during the year have been:—

Honorary Member: General Arthur Morin (lxii. 349).

Members: John Henry Abbey (*post*, p. 301; Francis Bell; Sir Thomas Bouch (*post*, p. 301); William Clark (*post*, p. 308); George William Drory; Frederick John Evans (*post*, p. 311); Henry David Furness (*post*, p. 313); John George Cockburn Curtis Godsman (lx. 393); John Lawton Haddan (lxii. 352); Thomas Higinbotham (*post*, p. 314); Maximilian Hjortsberg (*post*, p. 317); Edward Johnston (*post*, p. 319); Sir John Macneill; Alfred Ewald Schmid (lxi. 295); and John Sheldon Wilkinson (*post*, p. 320).

Associate Members: Frank Cheesman (lx. 405); George Coates (lxi. 897); William Lundy Crawford; William Boyd FitzGerald; John Godfrey Hochstaetter Godfrey; Charles Archibald Grieve (lx. 406); Thomas Howard Head (lxi. 297); John Henderson; Henry Burdon Hutchings; William Johnstone (lxii. 354); Edward Tickell Lang (lxii. 355); David Llewellin (lxii. 356); and Major Vidler (lxi. 299).

Associates: Edward Middleton Barry, R.A. (*post*, p. 322); William Freeman (*post*, p. 326); Captain Henry Sidney Freeman Haynes, R.E. (*post*, p. 327); Ralph Ward Jackson (*post*, p. 328); Charles Löwinger (*post*, p. 332); Matthew Andrew Muir (lxi. 298); Theodore Anthony Rochussen (lxi. 301); Edmund James Smith (lxi. 303); and Thomas Henry Wyatt (*post*, p. 334).

The resignations accepted have been—

Members: Alexander Grant; Thomas Edward Minshall; William George Owen; Thomas Frederick Parkinson; and George William Vivian.

Associate Members: Charles John Geneste; Lindsay Heath; and John Lillywhite.

Associates: Lieut.-Colonel George Chesney, R.E.; George Hayter Chubb; Captain Edward Harvey; Llewellyn Lloyd; Lieut.-Colonel William Henry Mackesy; Thomas Peacock; Lieut.-Colonel Edward Harding Steward, R.E.; and Isaac Wilson, M.P.

Although 159 Students were admitted in the session, the effective increase has only been 29, owing to the large number of 130 having been withdrawn from the list, namely, 29 by deaths or resignations, 51 by erasures due to non-payment of subscriptions or to having attained the age of 26 years, and 50 by having been elected Associate Members. There are now on the books 613 Students.

In regard to finance, the Abstract of Receipts and Payments, as certified by the Auditors, shows that the income proper for 1879-80 amounted to £11,877 16*s.* 2*d.*; the capital (including a legacy of £100 from the executors of Mr. Robert Napier) to £2,705 10*s.* 6*d.*; and the dividends on Trust Funds to £432 0*s.* 6*d.*, making the total cash received £15,015 7*s.* 2*d.*, or, with the balance from 1879, £15,723 15*s.* 2*d.* The general expenditure reached £11,896 4*s.* 1*d.*, of which £5,763 12*s.* 1*d.*, or nearly one-half, was incurred on account of the publications. The Telford Medals and premiums, the Manby premium, and the Miller Scholarships and prizes have absorbed £389 12*s.* 3*d.*, and a sum of £3,090 9*s.* 8*d.* was invested on capital account, leaving a cash balance on the 30th of November 1880 of £347 9*s.* 2*d.*

One of the first duties of the present Council was to consider whether the adverse judgment of the Court of Queen's Bench, in regard to the liability of assessment to local rates, should be acquiesced in, or whether the matter should be carried to the Court of Appeal. The highest legal advice was obtained, and this being to the effect that there was no reasonable probability that the judgment would be reversed, it has been deemed advisable to submit to it, the more so as the parish authorities agreed that, provided the appeal were not made, they would not enforce the payment of any rates prior to the commencement of the legal proceedings. In the detail of the expenditure, it should be explained that, the Institution having had to defray the costs of the late action and appeal against the payment of local rates, there are items which will not recur in future years, namely, arrears of rates for 1878 and 1879, and legal expenses, which together amounted to £661 6*s.*, and which have been discharged out of the year's income.

To compare the financial position of the Institution for the past year with what it was ten years ago, it may be remarked that under the head of capital, excluding the value of the premises (leasehold), furniture and library, the Trust Funds (nominal or par value) have increased from £12,119 15*s.* 8*d.* in 1870 to £14,642 13*s.* 10*d.* in 1880, and of the Institution investments, available for general

expenditure, from £10,656 1*s.* 8*d.* to £34,094 1*s.* 8*d.*, the combined funds amounting to £22,775 17*s.* 4*d.* in 1870, and to £48,736 15*s.* 6*d.* in 1880. This represents a capital of £13 7*s.* 6*d.* per head of the members of the corporation at the former date, and of £15 16*s.* 3*d.* at present. The library, furniture and effects of the Institution are insured in the Sun Fire Office for £20,000; the building is insured in the Guardian Fire and Life Office for £12,660. The Council have felt it their duty to encourage the growth of the capital account as much as possible, and to husband the resources of the Institution, in view of the expenditure which, sooner or later, must inevitably be incurred in enlarging the existing premises, or in acquiring new ones.

Contrasting next the income and expenditure at the two periods, it may be mentioned that the income amounted to £3 2*s.* per head of all persons belonging to and attached to the Institution in 1870, and to £3 4*s.* 7*d.* in 1880—the excess being due to the increase in the dividends on investments not in trust. Of the three chief items of expenditure, the cost per head for house and establishment charges was 17*s.* 5*d.* in 1870 and £1 0*s.* 5*d.* in 1880, the difference being more than covered by the disbursements due to the assessment for local rates previously alluded to; for "Minutes of Proceedings" it was £1 0*s.* 9*d.*[1] in 1870 and £1 11*s.* 3*d.* in 1880, although the annual number of volumes, of similar size, has been meanwhile increased from two to four; and for salaries 13*s.* 4*d.* in 1870 and 12*s.* 10*d.* in 1880. Presented in another form, the payments out of income last year may be approximately taken as follow, for "Minutes of Proceedings" 48 per cent.; for salaries and wages 20 per cent.; for house and establishment charges 18 per cent.; for office expenses 10 per cent.; and for the maintenance of the library 4 per cent. The comparatively small expenditure on the library is readily accounted for, by the fact that many books are obtained either as presents or as exchanges from other Societies.

During the past session Twenty-four Ordinary Meetings were held for reading and discussing Papers, when the average attendance was 63 Members, 61 Associate Members, 13 Associates, and 46 Students, being respectively 5·21, 4·74, 2·29, and 7·55 per cent. of the numbers belonging to each class on the 30th of November

[1] According to the accounts for the year ending November 30, 1870, this rate would amount to £1 13*s.*, but it may be explained that the item charged under this head included a volume that did not belong to that year.—Sec. Inst. C.E.

last, together 183 persons, or 4·96 per cent. of all classes. The average attendance of visitors was 56. At the Annual General Meeting, which is confined to Corporate Members, to consider the report, and to elect the Council and Officers, 158 Members, 109 Associate Members, and 34 Associates with corporate privileges, total 301, were present, being 10¼ per cent. of the numbers entitled to take part in that meeting. The average attendance at the Supplemental Meetings of Students was 27, or 4·43 per cent. of that class.

Four volumes of "Minutes of Proceedings" have been issued during 1880, for the most part of increased bulk as compared with former volumes, and more fully illustrated. This increase is, in a measure, due to the development of the discussions and to the addition of "Correspondence," which now forms a separate and easily distinguished division of Section I. Written contributions have not been discouraged, the idea being that it is better to have the views of any one experienced in the subject under debate in writing, than not to have them at all. This reception and recording of Correspondence is especially valuable in the case of non-resident members and others, who are thus afforded opportunities of enriching the literature of the profession with many interesting facts. In the last few years, foreign engineers of known authority have been invited to contribute to the proceedings, and these invitations have invariably been most courteously responded to. In this way the "Minutes of Proceedings" now comprise a much wider and a more varied range of practice and of experience. It must not, however, be supposed that in sanctioning the foregoing variation from precedent the Council desire to encourage such communications at the expense of the regular discussions. On the contrary, they are of opinion that *vivâ voce* debate is by far the most appropriate means of eliciting information, and they strongly urge its practice, even though it be accompanied by some personal inconvenience.

The paragraph in the last Annual Report, asking the members to supply short notes of engineering operations in which they are concerned, even when such memoranda may not be sufficient to justify the preparation of a Paper for reading, has already borne fruit, as may be seen from the greater number of short notices in Section II. of the Proceedings. Some of these Selected Papers have been of more than usual interest, and mention may be made of the Papers on "The River Nile," "Cleopatra's Needle," and on "The Practical Strength of Beams" (all by one Author), as typical examples of what is desired.

Appended to this Report will be found a list of the awards which the Council had the satisfaction to make, out of special funds bequeathed for the purpose, to the Authors of some of the Papers, which were either read at the Ordinary Meetings, or were printed in the Proceedings without being discussed, or were read at the Supplemental Meetings of Students. In the adjudication of the Premiums, the communication of Mr. Hayter, Member of Council, descriptive of "The Amsterdam Ship Canal," was not taken into consideration, in accordance with a well-understood custom; but the thanks of the Institution are nevertheless eminently due to Mr. Hayter for his valuable contribution.

The Council much regret the delay which has arisen, from unforeseen and unavoidable circumstances, in the issue of a General Index to the publications of the Institution. The Index is now so far advanced that they have reason to think it will be ready early next year. It will embrace the three 4to. volumes of Transactions, and fifty-eight out of the sixty-two 8vo. volumes of Minutes of Proceedings.

Fourteen Papers were received from Students, of which eight were read on as many evenings, and six were returned to the Authors as unsuitable. The Council have had the pleasure of awarding a Miller Scholarship and four prizes, and two of the five successful Papers have been printed in the Minutes of Proceedings. (Vol. lxii., p. 290, and p. 334.) From the establishment of the Student Class in the summer of 1867 to the present time, one hundred and twenty-five communications have been submitted by Students for reading at the Supplemental Meetings. These were at first carefully prepared and of excellent character, so that the Council had no hesitation in bestowing Miller prizes for all the Papers, twenty-five in number, contributed up to the end of the Session 1871-72, and several of the Papers were, by permission of the Council, printed by the Authors. Since then, however, the Council regret to notice that, with some important exceptions, there has been a falling off from the standard, insomuch that of the fifty Papers last sent in, it has been necessary absolutely to reject sixteen, and of the remaining thirty-four, twenty only have merited recognition.

During the past year nearly two hundred complete works have been presented to the library, besides numerous tracts and pamphlets. Mention may especially be made of the recent pre-

sentation by Mr. Charles Hutton Gregory, C.M.G., Past-President of copies of the contract, specifications, and drawings of the Ceylon Government railway extension, from Nawalapitiya to Nanu Oya; also of two large folio atlases of the São Francisco river, sent by Mr. D. S. de Saboia e Silva, Assoc. M. Inst. C.E.

The Institution has likewise added numerous valuable English and foreign technical works to the library by purchase. Perhaps the most interesting of these is a complete collection of the old editions of Vitruvius on architecture, in the Latin, English, French, German, Italian, and Spanish languages, commencing with a copy of the edition of 1496, and coming down to the edition dated 1832, embracing thirty-nine volumes in all.

The steady and marked progress of the library of late years must be a matter of great satisfaction to all the members, and may now be justly regarded as the acknowledged centre for reference and for study on all engineering subjects. The foreign serials regularly received number 152, and form a distinctive feature of the collection. Every book, pamphlet, or report presented to the Institution is immediately catalogued, and thus becomes forthwith an integral part of the library, accessible to all. Members living abroad should do their utmost to prevail on the governments and authorities of the countries they reside in to supply the Institution with the State documents and official reports on engineering issued by them.

While on this subject the members must be again reminded of the obligation entered into on admission, either to offer an Original Communication, or to present some scientific work to the library, within twelve months of their election. At the commencement of the past session special attention was directed to this engagement, and in the result donations in money to the library fund £200 in excess of the usual receipts were obtained.

Several friends and colleagues of Mr. Charles Hutton Gregory, C.M.G., Past-President, being desirous of showing their high opinion of his professional career, invited him to sit for his portrait, with a view to its presentation to the Institution, as a lasting record of personal regard and esteem. A Committee was accordingly formed to receive subscriptions, and the portrait painted by Mr. John Collier, is now offered to the Institution, by the Subscribers, in terms of the original proposal.

In the month of August the President received official intimation from the Privy Council Office that a petition had been presented

to the Queen in Council, for the grant of a Royal Charter of Incorporation, to the Society of Telegraph Engineers, and the President's opinion was invited as to whether the provisions contained in the draft charter were such as to interfere in any way with the rights and privileges of this Institution. As in the unanimous opinion of the Council no just or sufficient reasons existed for the grant of a second charter within the same profession, they embodied their objections to such a proceeding in a letter, of which the following is a copy :—

The Institution of Civil Engineers.

Established 1818. *Incorporated by Royal Charter*, 1838.

25, Great George Street, Westminster, S.W.,

23*rd August*, 1880.

C. L. PEEL, Esq., Council Office.

Sir,

In answer to your letter of the 13th August, directed to the President of this Institution, inviting observations upon a Petition that had been addressed to the Queen in Council, by five Members of the Society of Telegraph Engineers, praying for a Royal Charter of Incorporation, and accompanied by a Draft of such proposed Charter, I am instructed by the Council of the Institution of Civil Engineers to submit to you the following statement :—

In the year 1828, ten years after the foundation of this Institution, a Royal Charter of Incorporation was conferred (a copy is enclosed), which recites, among other things, that Thomas Telford and others had formed themselves into "a Society for the general advancement of Mechanical Science, and more particularly for promoting the acquisition of that species of knowledge which constitutes the profession of a Civil Engineer, being the art of directing the great sources of power in nature for the use and convenience of man;" and the Charter then goes on to give illustrations, by such instances as at that time were available and pertinent, of the manner in which the Civil Engineers of those days did direct the great sources of power in nature.

Among these instances there is not, as a matter of course, in the year 1828, to be found Telegraph Engineering, neither is there to be found Railway Engineering. But the practice of the Institution has always been to regard its Charter as empowering it, and indeed obliging it in the faithful discharge of its duties, to embrace within the scope of its functions every subject of Engineering as it arose, with the exception of those relating to military science; and thus it is that Railway Engineering and Telegraphic Engineering have been dealt with by the Institution, although no mention of those particular branches of Engineering is to be found in its Charter. A reference to the sixty volumes of "Minutes of Proceedings" of the Institution, will prove how thoroughly this statement is justified by the facts.

Great care is taken by the Council in ascertaining that those who are admitted to the membership of the Institution are persons properly qualified, in some branch of engineering, to warrant the Council in conferring that distinction; but assuming the candidates to be duly qualified, there is no limit to the number of members, and thus the Institution has on its roll gentlemen eminent in telegraph engineering, and representatives of this branch are upon its Council. The List of

Members, a copy of which is sent herewith, will serve to show that all the leading members of every branch of the profession, and whether practising at home or in the Colonies, belong to this, the parent Institution.

Notwithstanding, however, the catholic spirit in which the Institution has always acted, it has been found convenient, by persons interested in special sections of engineering, and particularly in respect of detail, to establish other societies, such as the Institution of Mechanical Engineers, the Institute of Naval Architects, the Iron and Steel Institute, the Society of Telegraph Engineers, and the Association of Municipal and Sanitary Engineers and Surveyors. The Institution of Civil Engineers, far from discouraging such societies, has always welcomed them, and with the exception of the Institute of Naval Architects, each of the societies mentioned has availed itself of the use of the house of the Institution, which is afforded to them without charge of any kind, for the purposes of their general meetings; and the Society of Telegraph Engineers has, as a matter of fact, never held its general meetings elsewhere.

It probably is desirable that these societies should have some legal status, but there is no need of a charter to give them this. In fact, the petitioners themselves recognise that such a status may be obtained under the 23rd section of "The Companies Act of 1867;" and, as bearing on this subject, reference may be made to the Institution of Mechanical Engineers, the oldest and most important of these bodies, which has availed itself of the powers and privileges conferred by this Act.

It not being a necessity that a charter should be granted for the purposes of legal recognition, it is submitted by the Council of this Institution that it would neither conduce to the public weal nor to the welfare of Engineers generally, that persons engaged in the pursuit of any branch of engineering, however useful, should have granted to them separate and distinct powers from those already conferred upon the whole body of Civil Engineers.

The Institution of Civil Engineers has been recognised ever since its establishment, and more particularly since the granting of its charter, by the British Government, by the Houses of Parliament, and also by foreign powers, as the representative body of the engineering profession in the United Kingdom. The Council of this Institution exercise, as already stated, great care in the selection of persons whom they admit to the privilege of membership, and the diploma of Member of this Institution is well known and highly appreciated, not only in the United Kingdom but in foreign countries and in the British colonies, as a certificate of the standing of the person holding it; and it is for this, among other reasons, that it would be undesirable there should be any question as to what chartered institution had granted a diploma for pursuits connected with civil engineering. Further, the Council submit that it is neither expedient nor advisable that any society, having like objects with those which the Council believe have been faithfully and honestly carried out by the Institution of Civil Engineers, should be incorporated by royal charter.

Moreover, it appears to the Council that the Society of Telegraph Engineers as a body has itself felt the force of these considerations, inasmuch as the petition is not that of the Society nor of its Council, nor even of its present President, but it is the petition of five members only, comprising one Past-President out of the number of distinguished men who have already occupied the chair (two of whom are members of the Council of this Institution), one Vice-President out of four, one member of Council out of twelve, and the Hon. Treasurer and the Hon. Secretary.

Under these circumstances it seems to the Council of this Institution not improbable that the petition has been presented by a few of the members of the Society of Telegraph Engineers, in order to comply literally with the desire of the late Mr. Carter, when he made his gift of the Ronalds Library, referred to in the petition; and they desire to point out that, if, as they trust, this application on the part of the Society of Telegraph Engineers to the Queen in Council be unsuccessful, that society will not suffer thereby, as their non-success will not divest them of the library, the deed of gift stating that, in the event of a royal charter not being granted, there are other modes by which the Society of Telegraph Engineers can put itself into a position to legally hold property, including the library.

In conclusion, the Council of this Institution desire to express their earnest hope that the Queen in Council may not see fit to accede to the prayer of the petitioners, and to request that if, after consideration of the facts herein mentioned, any doubt should still be entertained as to the propriety of refusing the prayer of the petition, the Council of this Institution may be permitted to attend, by a deputation, in explanation and in support of this statement.

I have the honour to be, Sir,
Your obedient servant,
JAMES FORREST,
Secretary.

As will be seen from the letter itself, this action of the Council did not arise from any want of friendly feeling towards the Society of Telegraph Engineers; indeed the Council can unhesitatingly say, for their predecessors and themselves, that the Institution has always shown a readiness and a desire to promote the welfare and prosperity of that Society. The Council have reason to believe the applicants were informed that Her Majesty could not grant the Charter prayed for in the petition.

In concluding this report, the retiring Council trust that all the members will, in conjunction with the incoming Council, continue to labour for the advancement of the Institution, bearing in mind that by its means not only is the science of Civil (civilian) Engineering everywhere promoted, but that its members, though scattered throughout the world, still have one common bond of union. Were any evidence needed that in many ways the Institution does confer great privileges on all who belong to it, that evidence would be afforded by the fact of the large number of candidates always seeking to be admitted to participate in those privileges.

ABSTRACT *of* RECEIPTS *and* EXPENDITU

RECEIPTS.

Dr.		£.
To Balance in the hands of the Treasurer	679 10 9	
,, ,, Secretary	28 17 3	
		708

Income.

	£.	s.	d.	
— Subscriptions:—				
Arrears	316	1	0	
Current	9,576	10	6	
Advance	119	0	6	
— Publication Fund	5	3	0	
— Library Fund	294	18	6	
— Minutes of Proceedings:—Repayment for Authors' separate copies, &c.	184	7	8	

— Dividends: 1 year on

£.	s.	d.	*Institution Investments.*			
4,750	0	0	Great Eastern Railway Four per Cent. Debenture Stock	186	0	10
3,000	0	0	London and North Western Ditto	117	7	6
1,500	0	0	London, Brighton, and South Coast Ditto	58	13	9
3,000	0	0	North Eastern Ditto	117	10	0
3,000	0	0	Great Northern Ditto	117	7	6
3,000	0	0	Lancashire and Yorkshire Ditto	117	10	0
3,000	0	0	Great Western Ditto	117	7	6
3,000	0	0	Caledonian Ditto	117	5	0
1,000	0	0	Midland Ditto	39	3	4
3,000	0	0	Highland Ditto	117	5	0
1,500	0	0	London, Brighton, and South Coast Railway Four and a Half per Cent. Ditto	66	0	5
3,000	0	0	Manchester, Sheffield, and Lincolnshire Ditto	132	3	8
1,344	1	8	New Three per Cents.	39	8	1
£34,094	1	8	Total nominal or par value.			

— Interest on Deposit Account	21 17 9	
— Sale of Old Materials	2 15 8	
— Benevolent Fund, Petty Disbursements, 1879	13 19 0	
		11,877 1

Capital.

— Admission Fees	2,109 9 0	
— Life Compositions	496 2 6	
— Exors. of the late Robert Napier	99 19 0	
		2,705 1
Carried forward		£15,291 1

from the 1ST DEC., 1879, *to the* 30TH NOV., 1880.

PAYMENTS.

Cr.

	£.	s.	d.	£.	s.	d.
GENERAL EXPENDITURE.						
By House and Establishment Charges:—						
Repairs	421	6	0			
Rent	658	7	0			
Rates and Taxes	452	13	0			
Insurance	41	16	6			
Fixtures and Furniture	241	17	2			
Lighting and Warming	88	2	8			
Tea, Coffee, &c.	65	13	3			
Assistance at Meetings	30	6	0			
Household Expenses	119	17	6			
				2,119	19	1
— Salaries	1,687	10	0			
— Clerks, Messengers, and Housekeeper	653	9	0			
— Donation to late Housekeeper	30	0	0			
				2,370	19	0
— Postage, Telegrams, and Parcels	146	17	5			
— Stationery, and Printing	445	14	3			
— Watt Medals	9	10	0			
— Diplomas	31	8	9			
— Annual Dinner (Official Invitations, &c.)	154	3	0			
— Legal Expenses, *re* Rates £392 9 7						
„ General 44 10 4	436	19	11			
				1,224	13	4
— Library:—						
Books	265	6	0			
Periodicals	52	18	8			
Binding	98	15	11			
				417	0	7
— Publication:—						
"Minutes of Proceedings"	5,508	2	1			
"General Index" Vol. I. to Vol. LVIII.	255	10	0			
				5,763	12	1
				11,896	4	1
CAPITAL INVESTMENTS.						
— £3,000 Highland Railway Four per Cent. Debenture Stock				3,090	9	8
Carried forward				£14,986	13	9

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS—*continued.*

Dr.				£.	s.	d.	£.	s.	d.
			Brought forward . .				15,291	14	8
			Trust Funds.						
To Dividends: 1 year on									
£.	s.	d.	*Telford Fund.*						
2,839	10	10	Three per Cent. Consols . .	83	8	4			
2,586	0	11	Three per Cent. Reduced . .	75	15	11			
2,377	10	5	Three per Cent. Consols (Unexpended Dividends) . .	69	16	8			
913	2	7	Three per Cent. Reduced (Ditto)	26	15	7			
8,716	4	9	Total nominal or par value.						
			Manby Donation.						
250	0	0	Great Eastern Railway Four per Cent. Debenture Stock . .	9	15	8			
			Miller Fund.						
3,125	0	0	New Three per Cents.	91	11	11			
643	19	8	Three per Cent. Consols (Unexpended Dividends) . . .	18	18	4			
1,355	14	11	Three per Cent. Reduced (Unexpended Dividends) . .	39	14	8			
5,124	14	7	Total nominal or par value.						
			Howard Bequest.						
551	14	6	New Three per Cents.	16	3	5			
							432	0	6
							£15,723	15	2

Summary of Investments.

Institution Investments			34,094	1 8
Trust Funds—				
Telford Fund	8,716	4 9		
Manby Donation	250	0 0		
Miller Fund	5,124	14 7		
Howard Bequest	551	14 6		
			14,642	13 10
Total nominal or par value . . .			£48,736	15 6

from the 1ST DEC., 1879, *to the* 30TH NOV., 1880.

PAYMENTS—*continued.*

Cr.	£.	s.	d.	£.	s.	d.
Brought forward . .				14,986	13	9
TRUST FUNDS.						
By Telford Premiums	246	19	1			
— Manby Premium	9	15	10			
— Miller Scholarships	80	0	0			
— Miller Prizes	52	17	4			
				389	12	3
— Balance Nov. 30, 1880, viz.:—						
Cash in the hands of the Treasurer . . .	317	9	7			
„ „ Secretary . . .	29	19	7			
				347	9	2
				£15,723	15	2

Examined with the Books and Securities and found correct.

(Signed) W. B. LEWIS
CHARLES DOUGLAS FOX } *Auditors.*

JAMES FORREST, *Secretary.*

1st of *December*, 1880.

PREMIUMS AWARDED.

SESSION 1879–80.

THE COUNCIL of The Institution of Civil Engineers have awarded the following Premiums:

FOR PAPERS READ AT THE ORDINARY MEETINGS.

1. A Telford Medal, and a Telford Premium, to Edwin Arthur Bernays, M. Inst. C.E., for his Paper on "Portland Cement Concrete, and some of its Applications."
2. A Watt Medal, and a Telford Premium, to Harry Edward Jones,[1] M. Inst. C.E., for his Paper on "The Purification of Gas."
3. A Telford Medal, and a Telford Premium, to John James Webster, Assoc. M. Inst. C.E., for his Paper on "Iron and Steel at Low Temperatures."
4. A Telford Medal, and a Telford Premium, to Frederick Augustus Abel, C.B., F.R.S., Assoc. Inst. C.E., for his Paper on "Explosive Agents applied to Industrial purposes."
5. A Telford Premium, to John Grant,[1] M. Inst. C.E., for his Paper on "Portland Cement; its Nature, Tests, and Uses."
6. A Telford Premium, to Maj.-General Henry Young Darracott Scott, C.B., R.E., F.R.S., Assoc. Inst. C.E., and a Telford Premium, to Gilbert Richard Redgrave, Assoc. Inst. C.E., for their Paper on "The Manufacture and Testing of Portland Cement."
7. A Telford Premium, to Charles John Wood, M. Inst. C.E., for his Paper on "Tunnel Outlets from Storage Reservoirs."
8. A Telford Premium, to William Henry Delano, Assoc. Inst. C.E., for his Paper on "The Use of Asphalt and Mineral Bitumen in Engineering."
9. The Manby Premium, to George Chatterton, M.A., Assoc. M. Inst. C.E., for his Paper on "The Main Drainage of Torquay."

[1] Have previously received Telford Medals.

FOR PAPERS PRINTED IN THE PROCEEDINGS WITHOUT BEING DISCUSSED.

1. A Telford Medal, and a Telford Premium, to Benjamin Baker, M. Inst. C.E., for his Papers on "The River Nile," "Cleopatra's Needle," and "The Practical Strength of Beams."
2. A Telford Medal, and a Telford Premium, to Joseph Lucas, for his Paper on "The Hydro-geology of the Lower Greensands of Surrey and Hampshire."
3. A Telford Premium, to Harco Theodorus Hora Siccama, M. Inst. C.E., for his Paper on "The Delta of the Rhine and the Meuse in the Netherlands."
4. A Telford Premium, to Joseph Miller Wilson, M. Inst. C.E., for his description of a "Bridge over the Monongahela River, at Port Perry, Pa., U.S.A."
5. A Telford Premium, to Frederic Eliot Duckham, M. Inst. C.E., for his Paper on "The Thames Steam Ferry between Wapping and Rotherhithe."
6. A Telford Premium, to George Moyle, late Stud. Inst. C.E., for his Paper on "The Platelaying of the Jacobabad or broad-gauge section of the Kandahar railway."

FOR PAPERS READ AT THE SUPPLEMENTAL MEETINGS OF STUDENTS.

1. The Miller Scholarship, to Henry Selby Hele Shaw, Stud. Inst. C.E., for his Paper on "Small Motive Power."
2. A Miller Prize, to John Augustus Thompson, Stud. Inst. C.E., for his description of the "Light Draught Steel P.S. 'Terranora,' for ocean and river navigation."
3. A Miller Prize, to Hans Ditlev Fabricius, Jun., Stud. Inst. C.E., for his Paper descriptive of the "Calais Harbour Improvements."
4. A Miller Prize, to Horace Allen, Stud. Inst. C.E., for his Paper on "The Manufacture of Bessemer Steel Rails."
5. A Miller Prize, to Lindsay Burnet, Stud. Inst. C.E., for his Paper on "Dredging Appliances."

SUBJECTS FOR PAPERS.

Session 1880–81.

The Council of The Institution of Civil Engineers invite communications, of a complete and comprehensive character, on any of the Subjects included in the following list, as well as on other analogous questions. For approved Original Communications, the Council will award Premiums, arising out of special Funds bequeathed for the purpose, the particulars of which are as under:—

1. The Telford Fund, left "in trust, the Interest to be expended in Annual Premiums, under the direction of the Council." This bequest (with accumulations of dividends) now produces £260 annually.

2. The Manby Donation, of the value of about £10 a year, given "to form a Fund for an Annual Premium or Premiums for Papers read at the meetings."

3. The Miller Fund, bequeathed by the testator "for the purpose of forming a Fund for providing Premiums or Prizes for the Students of the said Institution, upon the principle of the 'Telford Fund.'" This Fund (with accumulations of dividends) now realises £150 per annum. Out of this Fund the Council have established a Scholarship,—called "The Miller Scholarship of The Institution of Civil Engineers,"—and are prepared to award one such Scholarship, not exceeding £40 in value, each year, and tenable for three years.

4. The Howard Bequest, directed by the testator to be applied "for the purpose of presenting periodically a Prize or Medal to the author of a treatise on any of the Uses or Properties of Iron, or to the inventor of some new and valuable process relating thereto, such author or inventor being a Member, Graduate, or Associate of the said Institution." The annual income amounts to rather more than £16. It has been arranged to award this prize every five years, commencing from 1877. The next award will therefore be made in 1882.

The Council will not make any award unless a communication of adequate merit is received, but will give more than one Premium if there are several deserving memoirs on the same subject. In the adjudication of the Premiums no distinction

will be made between essays received from any one connected with the Institution (except in the cases of the Miller and the Howard bequests, which are limited by the donors), or from any other person, whether a Native or a Foreigner.

LIST.

1. The Frictional Resistance of Various Soils on Piers and Piles.
2. The most useful Sections of Rolled Iron for structural purposes, having regard to economy of material combined with strength.
3. The present systems of making Steel for Railway purposes, and the properties and character of the material.
4. Machinery for Steel-making by the Bessemer and the Siemens processes.
5. The Tempering of Steel, and the influence thereby produced on its strength.
6. Experiments on the Strength of Materials used in construction, with descriptions of the Testing Machinery employed to ascertain the same.
7. The methods of protecting Metal-work exposed to Corrosion, with examples.
8. The comparative effect of "dead" and "live" loads in straining materials and structures, with the factor of safety considered desirable for various proportions of such loads.
9. The Forms of Staging, Scaffolding, and Centering used for the support of structures during erection.
10. The modern practice of Bridge-building in Germany, especially with reference to the details of construction and the substitution of bar and angle iron for wide flange-plates.
11. The different methods of Erecting Metallic Bridges, with examples of Rolling-over, Building out, Lifting bodily, &c.
12. The Design and Construction of a Steel Bridge, with particulars of the Weight and Cost, and of the tests to which it has been subjected, compared with an Iron Bridge of the same span.
13. The Action of High Winds on lofty and exposed structures, and the best method for determining the force of the wind.

14. The Comparative Cost of Transport by land and by water.

15. The resistance to Traction of Vehicles on Roads.

16. The best system of Working Suburban Passenger Traffic on Railways.

17. The most suitable Motive Power for Underground Railways.

18. The Resistance on Railway Curves, and recent expedients to diminish the same by lubricated tires, divided axles, loose wheels, or otherwise.

19. The Measures hitherto taken, and still necessary, for the relief of the Midland and Eastern counties of England from Floods.

20. The Flow of Water through Pipes and Conduits, with experiments in verification of the existing formulæ, and suggested amendments and improvements.

21. The Mechanical Separation and Chemical Treatment of Sewage, with analyses of the effluents and of the sludge, and statements of cost in proportion to population and ratable value.

22. The modes of regulating the action of Storm Overflow from Sewers, and the Flushing of Sewers.

23. The methods used for determining the Discharge of Rivers, with a description of the Floats and Current Meters employed for the purpose.

24. The Works carried out on the Continent of Europe for the Improvement of Rivers, and of Inland Navigation generally.

25. The Design and Construction of Building Slips for large vessels.

26. The Construction of Tide Gauges, and the usual method of carrying out a systematic series of Tidal Observations.

27. The type of Steam Engine best adapted for ordinary factory purposes, in respect to economy in the use of steam, as well as in first cost, and in cost of maintenance.

28. The best method of Testing Steam Engines (independent of their boilers), having regard to accuracy of the results, and ease with which the tests can be carried out.

29. The modern practice in the design and construction of Boilers.

30. The Prevention of Smoke from furnaces and domestic fire grates.

31. The use of Compressed Air as a Motive-power, particularly as applied to machinery in mines, and for traction on tramways and in tunnels.

32. Wind and Water as Motive-powers, compared with Steam-power, and the Motors most suitable for utilising them.

33. The various descriptions of Pumps employed for Raising Water or Sewage, and their relative efficiency.

34. The different systems of Lifts in use in Warehouses and in Dwellings.

35. The design and most suitable materials for the construction of Bins for Warehousing Grain.

36. Machinery and Vessels for High-speed Steam Navigation.

37. The special Construction of Vessels for the reception of Railway Trains, indicating the Arrangements for the shipping of such Trains on their own wheels at various states of the tide.

38. The relative Loss of Power due to Friction in various parts of Machinery.

39. The various classes of Lubricants, with records of Experiments, showing their relative values, and a description of the mode of testing them.

40. The Methods and Machinery employed in Sinking and in Working deep Coal Mines.

41. Coal Depôts for Ocean Steamers, the various points involved in their management, and the methods of preserving large quantities of coal from deterioration.

42. The Methods employed in securing large and irregular-shaped mineral workings, for example—the Almaden Mines, the Great Comstock Lode, &c.

43. The combined use of Fire-brick, Iron, and other materials for resisting High Temperatures in Blast Furnaces, Kilns, Pottery Ovens, and similar structures.

44. The Disposal and Utilisation of Slags from various smelting processes.

45. The Management of Underground Waters in mining districts, and the relative economy of distributed or trunk pumping engines, adits, &c., in particular cases.

46. On proportioning Mains for the distribution of Water and of Gas.

47. The Employment of the Electric Current for the Transmission of Sound, and the use of the Telephone for practical purposes.

Instructions for Preparing Communications.

The Essays should be written in the third person, and be legibly transcribed on foolscap paper, on one side only, leaving a margin on the left side, in order that the sheets may be bound. Every Paper must be prefaced by a concise Abstract.

Illustrations, when necessary, should be drawn on tracing paper, to as small a scale as is consistent with distinctness, and ready to be engraved. When an illustrated communication is accepted for reading, a series of Diagrams will be required sufficiently large and boldly coloured to be clearly visible at a distance of 60 feet. These Diagrams will be returned.

Papers which have been read at the Meetings of other Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

The Communications must be forwarded to the Secretary of the Institution, from whom any further information may be obtained.

Charles Manby, *Honorary Secretary.*
James Forrest, *Secretary.*

The Institution of Civil Engineers,
25, *Great George Street, Westminster, London, S.W.*
October, 1880.

EXCERPT BYE-LAWS, SECTION XV., CLAUSE 3.

"Every Paper, Map, Plan, Drawing, or Model, presented to the Institution, shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same in any way and at any time they may think proper. But should the Council refuse or delay the publication of such Paper beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. Except as hereinbefore provided, no person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

NOTICE.

It has frequently occurred that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would therefore emphatically repeat, that the Institution, as a body, must not be considered responsible for the facts and opinions advanced in the Papers or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be regarded as an expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

ORIGINAL COMMUNICATIONS

RECEIVED BETWEEN DECEMBER 1, 1879, AND NOVEMBER 30, 1880.

AUTHORS.

Abel, F. A. No. 1,713.—Explosive Agents applied to Industrial Purposes. (Vol. lxi., p. 58.)

Agudio, T. No. 1,708.—Rack Railway, worked by Endless Ropes, for Steep Inclines. (Vol. lx., p. 380).

Apjohn, J. H. No. 1,693.—The Midnapore Canal. With 17 Drawings and Tracings.

Baker, B. No. 1,698.—Railway Springs.

——— No. 1,699.—Cleopatra's Needle. (Vol. lxi., p. 233.)

——— No. 1,705.—The River Nile. (Vol. lx., p. 367.)

——— No. 1,706.—The Practical Strength of Beams. (Vol. lxii., p. 251.)

——— No. 1,759.—The Actual Lateral Pressure of Earthwork.

Bell, J. R. No. 1,682.—The Empress Sutlej Bridge. With 3 sheets of Drawings.

——— No. 1,733.—The First Section of the Kandahar Railway. (Vol. lxi., p. 274.)

Bernays, E. A. No. 1,689.—"Portland Cement Concrete, and some of its Applications." (Vol. lxii., p. 87.)

Blyth, B. H. No. 1,748.—The Caledonian Railway New Central Station, Glasgow, and the Lines leading to it. With 11 Drawings.

Boswell, St. G. J. No. 1,723.—Dredging and other Plant employed on the Quebec Harbour Works. (*Post*, p. 265.)

Boult, W. S., and Potts, J. J. No. 1,754.—Seacombe Ferry Improvement Works. With 20 Drawings, a Map, and 6 Specifications.

Bovey, H. T. No. 1,730.—Cribwork in Canada. With 12 Drawings and a Model. (*Post*, p. 268.)

Boyle, R. V. No. 1,685.—Descriptive Account of the Rokugo River Bridge and Foundations, on the Tokio and Yokohama line of the Imperial Government Railways of Japan. With 3 Photographs and 5 Tracings.

Brown, T. F., and Adams, G. F. No. 1,725.—Deep Winning of Coal in South Wales. With 35 Drawings.

AUTHORS.

Browne, W. R. No. 1,738.—The Relative Value of Tidal and Upland Waters in maintaining Rivers, Estuaries and Harbours.

Bruff, P. J. No. 1,722.—The Jumna Bridge, Rajpootana (State) Railway, Agra. With 2 sheets of Drawings.

Churchward, W. P. No. 1,743*a*.—The Monte Penna Wire Ropeway. With 3 Drawings and Map. (*Post*, p. 273.)

Clarke, Colonel Sir A. No. 1,732*a*.—Note on the Kandahar Railway. (Vol. lxi., p. 273.)

Copperthwaite, H. No. 1,744.—Earthwork Slips on the Leeds and Wetherby Branch Railway. With 1 Drawing. (Vol. lxii., p. 285.)

Douglass, J. N. No. 1,740.—The Sevenstones Light Vessel. With 1 Tracing. (Vol. lxii., p. 288.)

Dymond, C. W. No. 1,697.—Description of a Canal Lock at Hell Meadow, near Wigan. With 3 Drawings.

Fowler, T. W. No. 1,724.—Continuous Girders.

Graffenried, C. de. No. 1,702. The Regulation of the Waters of the Jura. (Vol. lx., p. 363.)

Grant, J. No. 1,700.—Portland Cement, its Nature, Tests, and Uses. With Appendices and Illustrations. (Vol. lxii., p. 98.)

Harding, C. W. No. 1,708. Design for Iron Bridge at King's Lynn. With 2 Drawings.

Healey, B. D. No. 1,736.—On Impervious Pavements, and their Repairs.

Hedges, K. W. No. 1,703.—Notes on the principal Systems of Electric Lighting in use in England and in the United States. (Vol. lxii., p. 339.)

Higgin, G. No. 1,690.—Experiments on the Quantities of Material employed in Concrete and Brickwork.

——— No. 1,701.—Notes on the Composition of the Well waters of Buenos Ayres as compared with the River waters; with some remarks on the Rainwater used for House Consumption.

Jackson, M. No. 1,709.—Dredging operations on the Danube between Pressburg and Gönyö in Hungary. With a sheet of Tracings. (Vol. lx., p. 387.)

James, C. No. 1,761.—The Welland Canal Enlargement, and Port Colborne Harbour Works.

Johnston, R. E. No. 1,704.—New York Elevated Railways.

Jones, H. E. No. 1,692.—The Purification of Gas. (Vol. lxi., p. 1.)

AUTHORS.

Keating, E. H. No. 1,684.—On Fire Hydrants; with a description of one in use at Halifax, N.S. With 1 sheet of Drawings. (Vol. lx., p. 360.)

Langley, A. A. No. 1,764.—Diagram of Trial Rails on the Great Eastern Railway.

Longridge, J. A. No. 1,712.—The Piallee Bridge, Calcutta and South Eastern Railway. With a Tracing.

Lowe, J. H. No. 1,747.—A Description of the Protective Works erected to prevent the threatened outbreak of the South Rangitata river in New Zealand in 1878 and 1879.

Mackinnon, L. A. E. No. 1,717.—Sandy Island Lighthouse, Antigua, West Indies. With 2 Drawings. (*Post*, p. 255.)

Maxwell, J. P. No. 1,696.—New Zealand Government Railways. With Appendix and 4 Drawings. (*Ante*, p. 50.)

Morshead, W. No. 1,753.—Machinery for Crushing Metallic Ores.

Mosse, J. R. No. 1,720.—Ceylon Government Railways. With 3 sheets of Drawings, Map and Photograph. (*Ante*, p. 63.)

Moyle, G. No. 1,734.—The Plate-laying of the Jacobabad or Broad-gauge Section of the Kandahar Railway. (Vol. lxi., p. 286.)

Newman, J. No. 1,743.—Note on a Snow Plough. (Vol. lxi., p. 270.)

Parry, E. No. 1,756.—Earthwork Slips on the Nottingham and Melton Railway.

Roberts, W. M. No. 1,735.—Note on the São Francisco River. (Vol. lxi., p. 256.)

Rymer-Jones, A. M. No. 1,742.—The Temnograph. With a Drawing. (Vol. lxi., p. 268.)

Sandeman, J. W. No. 1,718.—New Ship Locks and other works for the Improvement of the River Weaver Navigation. With 9 Drawings. (*Post*, p. 261.)

Seyrig, T. No. 1,732.—On the different modes of erecting Iron Bridges. With 3 Tracings. (*Ante*, p. 151.)

Stooke, T. S. No. 1,710.—Rural Water Supply. With 3 Drawings. (Vol. lxi., p. 252.)

Target, J. L. F. No. 1,758.—Experiments on a new form of Module for Irrigation purposes. With 2 Drawings.

Unwin, W. C. No. 1,757.—The Coefficient of Friction of Air Flowing in Long Pipes. (*Post*, p. 297.)

Walker, B. No. 1,746.—On Machinery for Steel Making by the Bessemer and the Siemens Processes. With 8 Diagrams. (*Ante*, p. 2.)

AUTHORS.

Webster, J. J. No. 1,691.—Iron and Steel at Low Temperatures. (Vol. lx., p. 161.)

Weyrauch, J. No. 1,752.—On the Calculation of Dimensions as depending on the Ultimate Working Strength of Materials. (*Post*, p. 275.)

Whitley, H. M. No. 1,739.—Earthwork Slips on the Castle Eden and Stockton Railway. With 2 Drawings. (Vol. lxii., p. 280.)

Willotte, H. No. 1,740.—On the Removal of Sunken Rocks in Brest Harbour. With Note by H. Hersent. (Vol. lxi., p. 261.)

LIST OF DONORS TO THE LIBRARY.

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Bevan, Rev. James Oliver	1	11	6
Beynon, George William	2	2	0
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Brown, Oswald	10	10	0
Brown, Thomas Common	1	1	0
Burtchaell, Peter	1	11	6
Carey, Alfred Edward	1	1	0
Carpmael, Edward	3	3	0
Coles, Henry James	0	10	6
Cresswell, John	1	1	0
Creswell, Robert Edward	3	3	0
Crook, Henry Tipping	2	2	0
Dobson, James Murray	3	3	0
Fahey, Charles Swaine	10	10	0
Fenn, Arthur George	1	0	0
Forbes, James Staats, Jun.	5	5	0
Gandon, Charles	3	3	0
Garland, Walter Faithfull	3	3	0
Girdlestone, John Ward	2	2	0
Godfrey, William Bernard	5	5	0
Golla, Lucien Alexander	2	2	0
Goodwin, Singleton	1	0	0
Goudie, James Hunter	1	1	0
Hall, John Green	5	5	0
Hall, Joseph	2	2	0
Hayward, Joseph	2	2	0
Henderson, John James	1	1	0
Henslowe, Francis Boyle	5	0	0
Hindle, Joseph	5	0	0
Hodgson, Henry Tylston	3	0	0
Hogarth, David Francis	5	0	0
Horsley, Charles	5	5	0
Hughes, John Ellis	1	6	6
Hume, Edward Nathaniel	1	17	0

	£.	s.	d.
Hunter, John, Jun..	1	1	0
Hunter, Walter	2	2	0
Innes, Cosmo	1	1	0
Jessop, George	1	1	0
Johnson, John William	1	1	0
Jones, Isaac Matthews	3	3	0
Jones, William Henry	2	2	0
Latham, Edwin Davenport	5	5	0
Lee, Joseph John	1	1	0
Logan, John William	2	2	0
MacBride, Robert	2	2	0
MacGregor, Alfred Alexander	5	0	0
MacGregor, Alexander	2	2	0
MacGregor, Josiah	1	1	0
McLaren, John	2	12	6
Madeley, James Chatburn	5	0	0
Maxwell-Müller, Robert William	1	1	0
Maylor, William	2	2	0
Middleton, John Thomas	1	1	0
More, Charles James	2	2	0
Moyle, Samuel	3	3	0
Olive, William Thomas	1	1	0
Park, Edward Matthew	7	7	6
Parkes, Thomas Farmer	5	5	0
Pearson, Henry William	3	3	0
Prouse, Jun., Charles	1	1	0
Radley, John Alfred	1	1	0
Reade, Frederick Thomas	3	3	0
Richards, Edwin Melville	5	5	0
Richardson, John	5	5	0
Romanes, George	2	2	0
Ross, Alexander	5	5	0
Sadler, Ralph	1	1	0
Sheldrick, John Thomas	1	1	0
Smith, Guy	3	3	0
Smith, Henry Robert	2	2	0
Smith, James Thorneloe	2	2	0
Smith, Urban Armstrong	1	1	0
Stewart, John Tiffin	2	0	0
Stride, Arthur Lewis	5	5	0
Stubbs, William Henry	10	10	0
Surnburn, John	2	2	0

	£.	s.	d.
Sykes, Benjamin	21	0	0
Terry, Stephen Harding	1	1	0
Thornbury, Edward Barton	2	0	0
Tinney, William Upton	1	1	0
Vansittart, John Pennefather	1	1	0
Wade, John	2	2	0
Waring, Francis John	2	2	0
Webster, John	1	1	0
Weiss, Hubert August Otto	1	1	0
Welsh, Thomas Debell	2	2	0
West, Thomas Edward	2	2	0
Williams, George Phipps	10	10	0
Winstanley, George	2	2	0
Willcocks, George Waller	2	12	6
Yabbicom, Thomas Henry	2	2	0
	£294	18	6

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*** *This Council will continue till December* 1881.

SECT. II.—OTHER SELECTED PAPERS.

(Paper No. 1717.)

"Sandy Island Lighthouse, Antigua, West Indies."

By LAUCHLAN ALEXANDER ENTWISLE MACKINNON,
Assoc. M. Inst. C.E.

SANDY ISLAND is a small key situated 2 miles due west of "Ship's Stern" point, the southern promontory of, and which separates the harbour of St. John from, Deep Bay; the latter is the point where the West Indian and Panama Company's telegraph cable is landed. The island is 6 nautical miles from the city of St. John, and consists of a bank of coral sand about 2 acres in extent, several feet above the water-level, covered with scrub and a few cocoa-nut trees. It is immediately to windward of the much-dreaded Weymouth bank, which reaches from ¼ mile west of Sandy Island ½ mile south, and from which it is separated by a channel 16 feet deep. A submerged coral reef extends on the north, west, and south sides of the island several hundred feet into the sea; and over it on the southern portion, which rises to within 4 feet of the sea-level, landing is effected in small boats.

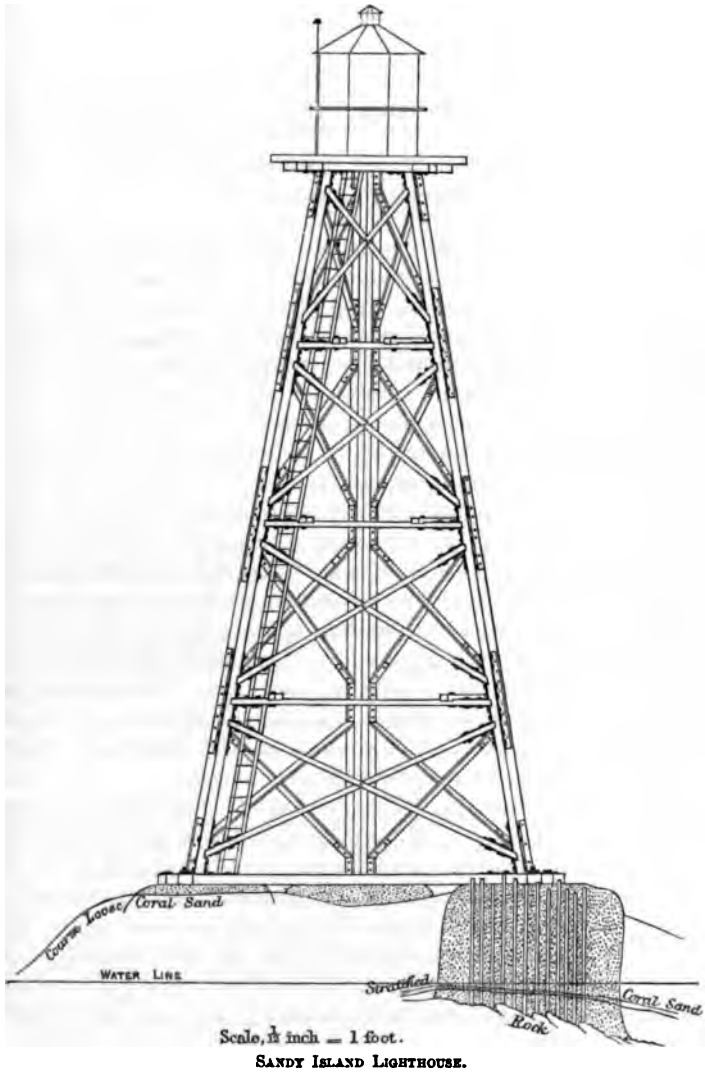
The Government of Antigua had contemplated the erection of a light on this island ever since the year 1828. The proposition was mooted by the inhabitants of St. John, in consequence of the loss on Christmas-day, 1826, of a sloop on the outer side of the Weymouth, with all on board except one person.

On the 14th of December, 1874, the Author, then Superintendent of Public Works in St. Kitt's, was ordered to proceed in the Colonial steamer "Union" to Antigua, there to prepare plans for and to erect a lighthouse on this key, with the utmost expedition, so as to induce the Royal Mail S.S. Company to land mails, passengers, and cargo at St. John, instead of, as theretofore, at English Harbour, the Royal Naval Dockyard, and thus obviate their conveyance unnecessarily for a distance of 14 miles overland to the city.

In undertaking such a work the prime factors to be considered were cheapness, efficiency, durability, and freedom from accident by fire or hurricane. The sand on the island is from 7 to 10 feet

deep, resting on a hard rocky formation, to make a substantial foundation in which would prove the most troublesome and costly part of the work, on account of the drifting of dry sand wherever

FIG. 1.



SANDY ISLAND LIGHTHOUSE.

excavations were attempted. Under such conditions plans were submitted to, and approved by, the Government of the Leeward

Islands. The Author was thereupon directed to proceed with the construction. The form of structure decided on (Fig. 1, p 256) was that of an open woodwork tripod, broad at the base and narrowing to the top, on which a wrought-iron lantern chamber was proposed to be erected; the whole construction was to be sufficiently substantial to enable the Government at a future date, if it so deemed necessary, to substitute a small lantern chamber and lamp, without the expense of a new tower being built. In carrying out the work, old boiler tubes were first driven through the sand and a thin bed of stratified coral, to the solid rock below the surface of the sea, the driving apparatus being the ordinary Abyssinian pump gear. These tubes were introduced in the form of three triangles, corresponding to the position of the uprights; a timber frame being inserted and driven down as the sand was excavated. When the excavations had been made inside each triangle of tubes to a depth of 4 feet, a second frame was introduced at the top, thus securing the tubes in position during the remaining period of time occupied in excavation. Bratticing boards were driven down behind the tubes to keep out the sand.

On reaching the rock, from 1 foot to 3 feet below the surface of the sea, Portland cement was thrown in and well mixed with the sand, as it oozed through the bratticing, in the proportion of 1 part of cement to 3 parts of sand. When this had thoroughly set, the lower framework was taken out, and a bolt at each angle, 8 feet long by 1½ inch in diameter, was placed vertically, head downwards, on this cement, a large washer of boiler-plate, 8 inches square, being over the bolt head; these bolts were then built in with coral junks broken from the surrounding reef, and brought up with the aid of a diver from the inside of the reef on the south of the island; the ballast of a wreck was similarly utilized. When the pillars had attained a height of 7 feet above the sea-level the bratticing was taken out, the tubes were filled with cement mortar, and the sand was excavated for a space of 2 feet outside the tubes—one side at a time. Bratticing was used to keep the sand out as before, the spaces being filled in with coral junks set in cement mortar.

The sill having been laid over the holding-down bolts, the superstructure of timber framework was commenced. This consists of three bays framed separately, which were put together at St. John, and afterwards taken to pieces and brought out in a boat. The main uprights are pitch pine timbers 45 feet long by 7 inches square in cross-section, into which are notched three intermediate beams, at intervals of 11 feet, of pitch pine 4 inches by 6 inches in

cross-section, and tied together with diagonal braces 5 inches thick by 4 inches wide, notched into each other at the points of intersection. The diagonals are let into the uprights, one from the outside and the other from the inside face; thus requiring less waste of strength by halving out the timber at the points of intersection, as, from the way they are put together, only 1½ inch out of the 5 inches thickness is cut out. Each bay, measuring in breadth 21 feet 2 inches at the base and 5 feet 8 inches at the plate, was, after having been carefully framed and fitted with iron straps, taken to pieces and shipped to Sandy Island, where the various pieces were towed ashore and put together on the foundation in a horizontal position. The first bay was hoisted to a vertical position by a spar 20 feet long, and an ordinary fall-tackle, and was held in place by stays made fast to two anchors laid in the coral reef. The second and third bays were then easily hoisted from the first. Having successfully erected the framework tower, and secured it by superadding the plate- and corner-ties, notched over and bolted to the beams, and the strap-irons being fixed on the sill and under the main holding-down bolts, the lantern framework was sent down. This consisted of a base of boiler-plate on which was bolted eight uprights of 2½ inches by ⅝ inch wrought-iron standards, to which had been welded T pieces, one to bolt to the sill, the other to the eaves-plate. At 2 feet 6 inches from the base-plate there is a centre table to which alternate horizontal and diagonal bars were riveted, on which to fix the lighting apparatus; and to prevent vibration, alternate diagonal rods of ⅝-inch round iron were riveted from the level of the foot of the glass frames to a centre table of boiler iron and diagonally to the foot of the opposite upright. The roof frame was made of similar material to the uprights, riveted to a plate similar to the centre table, from which it was found necessary to attach hooked movable rods to screw under the plate-iron centre table, inside of which the lamps could be held in position. These rods added greatly to the steadiness of the light, and completely stopped vibration. Under the plate-glass the lantern chamber was covered with plain galvanized iron riveted together; the roof had a double thickness of the same, and was surmounted with a small ventilator for the escape of heated air. For the ingress of air the centre of the base-plate was perforated with ½-inch holes, and, for the entrance of the light-keeper, by an oblong man-hole 18 inches by 24 inches. The sashes, in which are set the plates of glass 30 inches by 40 inches, are of wrought iron; the inside edge of the glass rests against a rib of ½-inch square iron, and is kept in place by a similar

strip fastened by studs so as to allow broken panes to be replaced without delay. The sashes are held in place by studs riveted to the inside of the frames, which pass through clamps made of wrought-iron bars 1 inch square, swaged in the middle so as to fit on the edge of the uprights, and secured by nuts through holes bored in the clamps.

The lighting is effected with kerosene oil. There are two cisterns arranged one over the other. Each cistern feeds six burners, behind which ordinary concave silvered glass reflectors are placed, and are held by a reflector holder, consisting of a round iron plate on adjustable legs, and under these hook-bolts hold the square rods in which the reflectors are set. The reflectors are so arranged, one over the other, that at every 30° one reflector is in full focus. The light on ordinary nights is seen at a distance of from 12 to 13 miles, being 56 feet above the sea level to the centre of the light, and it can usually be seen from Rodunda, 20 miles to the south.

The Author does not claim for this erection any peculiar merit. It is a purely colonial production, and answers the requirements of the place. His object in making the timber superstructure in three distinct bays was, that it was feared by the Colonial Government that during a hurricane, to which Antigua is especially liable from July to October, one or more of the uprights might be carried away by the sea. The form of structure admits of any one of the bays being taken out, renewed and replaced with safety without interfering with the light, or in anywise jeopardising the shipping interests of the island.

The means of access first adopted was that shown in Fig. 1, page 256; but between October 1875 and September 1876 it was altered so as to make the ascent less steep, although it is more open to danger in heavy weather. The object of the original design was to place the ladder in the position calculated to secure the attendant in the best manner should accident be imminent; whereas the present ascent is effected by a ladder sloping to the middle of each 6 inches by 4 inches beam, thereby attaining greater ease in the ascent.

The lighthouse, with the exception of the plate-glass, was completed in June 1875, at a cost of about £650 sterling, of which £150 went for boat-hire. The plate-glass arrived in August, and the light was regularly displayed from the 1st of October of the same year. West of the lighthouse, on the island, are the keepers' cottages, and at the extreme west of all the oil and provision stores, both of which were erected at an early date, and used during the

construction for the accommodation of the hands engaged in the work.

In September 1876, the Author was summoned to Antigua to repair damages to the foundations, caused by the hurricane of the 12th of that month. On arriving at Sandy Island the only damage discoverable was that the sea had washed away 4 feet out of the 7 feet of sandbank, and had exposed the foundations. On this occasion advantage was taken to increase the size of the pillars.

Although there is no antechamber for the supply of air under the lantern-chamber of the lighthouse, the manhole door of the iron lamp-chamber was open during the whole of the hurricane, when not a burner flickered, nor did any fog appear on the glass. The attendant retrimmed the lamp at midnight as usual, when the gale had just passed its worst. The gallery outside is reached by a ladder spiked to the outer posts nearest the original ladder.

The main object of this Paper is to demonstrate the facility with which a beacon can be erected in the tropics. The expense of maintenance is one and a half can of oil per week, about 14*s.*; two attendants, 21*s.*; chimneys, wicks, and sundries, 2*s.* 6*d.*; boat-hire, water, and provisions, 16*s.*: total, £2 13*s.* 6*d.*, or about £140 per annum.

(*Paper No. 1718.*)

"The River Weaver Navigation."[1]

By JOHN WATT SANDEMAN, M. Inst. C.E.

THE river Weaver, which rises in the south-west of Cheshire, and flows through the towns of Nantwich, Winsford, and Northwich, joins the estuary of the Mersey at Weston Point. Its total length is 51 miles, 21 of which are navigable. Along with its tributaries the Weaver drains about 550 square miles of land, or nearly one-half of Cheshire.

This river has been in existence as a navigation for a century and a half, and has played an important part in the commercial history of the county. Passing through the heart of the salt district, it affords a convenient waterway for the carriage and export of that article, of which 1,000,000 tons are annually conveyed along the river. The tolls levied upon the navigation amount to £60,000 per annum.

The salt is carried on the Weaver, and from thence on the Mersey to Liverpool, in barges and sailing flats, from which it is transhipped into sea-going vessels. At Winsford and Northwich about 100,000 tons of rock salt are mined annually, while 1,250,000 tons of manufactured salt are obtained from brine which overlies the upper bed of rock salt, and naturally accumulates there by the dissolving of the salt. The brine is pumped to the surface, and the salt obtained from it by evaporation. The removal of the brine is attended with considerable damage to land by the sinking which results, having extended to the depth of 70 feet within the memory of man. This causes the formation of lakes, connected with the river, which serve as storage reservoirs for the supply of the locks.

The first step taken towards the improvement of the river was in 1721, when three Cheshire landowners obtained an Act of Parliament to make it navigable from the Mersey to Winsford. By 1807 several locks and weirs had been built. In 1829 the Weston canal and a tidal basin at its junction with the

[1] Abstract by the Author of an Original Communication, which is accompanied by nine drawings, including a map and section of the river, details of the New Ship locks, the sluices, turbines employed to work the lock gates, &c.

Mersey had been constructed, and the navigation was divided into ten reaches or ponds with a single lock at each pond. Between 1843 and 1850 the locks below Northwich, and between 1850 and 1865, the locks above Northwich, were duplicated. Between 1865 and 1872 a system of river improvement, projected by Mr. E. Leader Williams, M. Inst. C.E., for the purpose of enabling sea-going vessels to reach Northwich, and to afford facilities for steam-towing, was commenced by him, including the widening and deepening of the Weston canal, and the construction of new locks at its upper and lower ends. Mr. Williams also originated the hydraulic canal lift at Anderton,[1] for the purpose of establishing direct water communication between the river Weaver and the Trent and Mersey canal.

Between 1872 and 1877 the Author carried out various improvements, including the hydraulic canal lift at Anderton, the construction of large sluices for the relief of floods, a new weir, deep-water river quays, &c., and lastly, two sizes of new ship locks at Saltersford[2] and Acton. The larger of these locks is 229 feet long by 42½ feet wide, and is capable of accommodating a vessel of 1,000 tons burden; the smaller is 220 feet long by 25 feet wide. The depth of water on the sills of both locks is 15 feet. Each lock has three pairs of gates, so as to enable only half the lock to be used when desired; the gates of the larger locks are opened by means of turbines, and those of the smaller locks by hand capstans and quadrant wheels. Each lock has six cylindrical sluices, two inlet, two outlet, and two central, the latter to empty the upper and fill the lower compartments of the locks when the central gates are used; two intermediate sluices are also provided, affording communication between the locks. The locks are built of Runcorn red sandstone ashlar, backed with rubble. The hollow and square quoins, sills, fender courses, and coping are of Anglesey limestone. Portland cement concrete was employed for the stop walls in the trenches at the gate sills, and under the central piers of the locks.

The lock gates are of greenheart and of English oak timber, the former being used for the heel- and mitre-posts, and the latter for the beams. The cleading is of American red pine. The gates are without rollers, but have caps of malleable cast iron upon their heel-posts, from which diagonal tie-bars extend upon both sides, and are secured to the lower ends of the mitre-posts, so as to sustain the overhanging weight of the gates. The gate pivots and shoes are also of malleable cast iron, turned to fit each other. The gate

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlv., p. 107. [2] *Ibid.*, vol. lv., p. 147.

anchor-straps are secured to cast-iron anchor-plates bolted to the masonry. The gate pivots and caps are eccentric to the hollow quoins to obviate friction upon the masonry; this enables the small lock gates to be opened or closed by one man in about thirty seconds.

By means of turbines, constructed upon Schiele's[1] principle, the large lock gates are easily opened or closed in about twenty seconds. The chief advantage of the turbine over other motors is, that by its means the head of water at the locks, a power which costs nothing, can be employed. The turbines are placed in circular wells, adjoining those of the chain capstans, and the shafting of both being vertical, the latter are driven without the intervention of bevelled gearing. The capstans are situate at the levels of the gate fastenings, and chains lead from them over carrying rollers to the gates. The main supply and discharge pipes are 20 inches, and the branch pipes to each turbine 16 inches, in internal diameter. The turbine wheels are 18 inches in diameter, with twenty double buckets 2 inches in depth; they have exit orifices $\frac{7}{8}$ inch wide, giving a total area of 70 square inches, and are designed to work at one hundred and seventy-three revolutions per minute. There are sixteen ports in the turbine casing, having a total area of 60 square inches, capable of being diminished to the extent of $\frac{5}{16}$ths by five adjusting slides. The quantity of water consumed by each turbine is 270 cubic feet per minute.

A form of equilibrium sluice, worked easily by hand, has been adopted for the locks, in preference to the ordinary sliding sluice, which would have necessitated the employment of steam or of hydraulic power. Sluices upon a similar principle had been previously employed by Mr. Hawksley, Past-President Inst. C.E., at the Liverpool waterworks. The sluice, in the present instance, was designed by Mr. F. G. M. Stoney.[2] It consists of a wrought-iron cylinder, open both at the top and at the bottom; upon the bottom an annular casting is bolted, having a conical face turned to fit a cast-iron seat, which is also turned and is in two parts, the lower cemented into the masonry, and the upper removable for refacing, should such at any time be required. The top of the cylindrical sluice being above the upper water-level, the pressure due to the head acts only around its circumference, and in conse-

[1] *Vide* "Mechanics of Engineering and of the construction of machines." By P. J. Weisbach, vol. ii., p. 516. New York, 1877.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. lx., p. 85.

quence equilibrates itself, so that the sluice can be raised or lowered without being affected by the water-pressure. The total weight to be raised is only that of the cylinder and fittings attached, and as these are counterbalanced, and as the height of lift is only 16½ inches, the sluice is easily raised or lowered by one man in about four seconds. The sluices for the large locks are 5 feet 6 inches, and for the small locks 5 feet 3 inches, in diameter of opening. The new locks and cuttings were commenced in 1874; but for financial reasons their progress was delayed, so that they were not opened for traffic until 1878.

From the drawings accompanying this communication two have been selected for reproduction (Plate 11), namely, the map of the navigation, and the details of the New Ship Locks.

(*Paper No. 1723.*)

"Dredging and other Plant employed at the Quebec Harbour Works."

By St. George James Boswell, Assoc. M. Inst. C.E.

In America what is known as the clam-shell dredge is extensively used. The longitudinal section (Plate 12, Fig. 1), will serve to show the position of the machinery, while Figs. 2 to 10 show the details of a bucket similar to the one on this dredge, though of smaller capacity. This form of dredge is eminently suited for digging in soft material, as in mud, or comparatively loose sand, where boulders are embedded in the material, as it is capable of lifting boulders that would disable an elevator dredge by tearing off the ladder buckets. It can in no case be disabled by coming in contact with a boulder, its rapidity of motion giving it a great advantage over the ordinary dipper dredge.

In dredging for the Quebec Harbour Improvements, where the material to be excavated consists of closely compacted sand and boulders, the average amount taken out by the clam-shell in ten hours is 1,200 cubic yards, the dredge consuming in that time 3,500 lbs. of coal; and it is estimated that in mud, with the same consumption of coal, the clam-shell would be capable of moving 2,000 cubic yards. The dipper dredge, working in the same material, removes on the average 1,000 cubic yards in ten hours, burning in the same time 4,000 lbs. of coal, and is estimated, under similar conditions, to be capable of moving 1,500 cubic yards of mud. These dredges are worked with an average of 60 lbs. pressure of steam per square inch. The clam-shell dredge has two cylinders 16 inches in diameter and of 22 inches stroke. The dipper dredge, to which it has been compared, and which is similar to the ordinary steam navvy, has two double engines, one of 15½ inches diameter and 22 inches stroke, and the other of 6 inches diameter and 12 inches stroke: the former is used to work the dipper bucket, the latter to revolve the crane. In the clam-shell dredge the drums for the hoisting and lowering chains are supplied with friction gear, so that the engine does not require to be reversed, the weight of the bucket being sufficient, on the friction gear being thrown out, to lower it.

The lower of the two shafts of the bucket (Figs. 10 and 11) is provided with three drums, *a*, *b*, *b*, the chains pressing round *b* and *b* being attached to the upper movable shaft, above which they are led into one, and form what is known as the lowering or opening chain, the upper shaft being capable of a vertical movement in seats in the side frame; another chain is passed in the reverse direction round the drum *a*, and is known as the hoisting or closing chain. When the bucket is to be lowered, its weight is allowed to come on to the lowering chain, until the bucket reaches the material to be dredged; it is then slackened, and the hoisting-chain is tightened, thus drawing down the movable shaft and closing the bucket. When the pull on the hoisting-chain exceeds the resistance due to the weight of the bucket and the resistance and weight of material, the bucket rises, and swings towards the side of the dredge to which the hoisting-chain is led. On the bucket reaching the proper position for dumping, the hoisting-chain is slackened, and the weight of the bucket is allowed to come on the lowering-chain, so that the movable shaft is drawn up, thus opening the bucket, which at the same time swings in the opposite direction, or towards the lowering-chain. This movement of the bucket can be checked in any position by the tightening or loosening of either chain. Fig. 7 shows the general mechanical arrangements of the four types of bucket principally used.

In connection with the dipper dredge a Hercules revolving derrick (Figs. 12 to 16), is used on the Quebec Harbour Improvements. Figs. 12, 13 and 14 show the mast and boom seat of the derrick, which revolves on twelve cones, working in a casting supported by a platform resting on the car-truck. The derrick is provided with two booms, each having a reach of 110 feet from the centre of the platform. Tubs are attached to the ends of the booms, by means of chains which pass round the hoisting drums on the platform, so that the tubs can be lowered on to a deck-scow placed alongside the dredge, when they are filled by the dipper; they are then hoisted up and swung round, being dumped when in position by a trip line led from trip hooks on the tubs to the platform of the derrick. The revolving and hoisting are done by independent engines; the revolving machinery consists of a pair of cylinders, 6 inches in diameter, with a length of stroke of 10 inches, connected by bevel gearing with a vertical shaft, at the lower end of which is a pinion working with a circular rack of 12 feet in diameter. The hoisting machinery consists of a pair of cylinders, 8 inches in diameter, with a length

of stroke of 14 inches, connected with two friction drums working independently of the revolving machinery, thus enabling the operator to revolve and hoist the load simultaneously.

This derrick makes on an average fifty revolutions per hour, being capable of moving about 1,500 cubic yards of material in ten hours, consuming 2,000 lbs. of coal in the same time. The derrick was formerly supported on a double track laid on small crib blocks, the blocks and track being placed in advance of the derrick as it required shifting. A deck-scow, or caisson supplied with valves, was subsequently substituted for this movable track, the derrick being moved at high water. This is done by opening the valves at low water until the scow is empty of water; the valves are then closed, and the derrick, as soon as the scow floats, is towed into the new position, when the valves are opened and the caisson sunk.

Figs. 17 to 22 represent a box used for mixing the concrete. It is revolved on its diagonal axis by means of worm gear connected by belting with the shaft.

The chief engineers of the Quebec Harbour Improvements are Messrs. Kinipple and Morris, MM. Inst. C.E.; the resident engineer is Mr. Woodford Pilkington, M. Inst. C.E.; and the Author is the assistant engineer.

The Paper is accompanied by several drawings, from which Plate 12 has been prepared.

(*Paper No. 1730.*)

"Cribwork in Canada."[1]

By HENRY TAYLOR BOVEY, M.A., Assoc. M. Inst. C.E.

THE use of cribs for piers, dams, &c., is common in all parts of America, as they are well adapted to meet the requirements of many descriptions of canal and river work. The cribs are merely open or close boxes, made of timbers strongly framed together; they may be of any size, are easily built, cost little, and are most durable. Indeed, the part of the crib below low water may be said to be almost everlasting, while the life of the upper part varies from ten to twenty-five years, and depends upon the kind of timber and the conditions to which it is subject. The timbers employed in their construction are generally brought to the site in rafts; they are of all lengths, and have scantlings of from 10 inches to 15 inches square; they should be straight, and free from shakes, sap-wood, unsound knots, and other defects. White pine, as a rule, is used above low-water line, as being the most durable; but below this level any good timber, such as pine, oak, ash, tamarac, elm, cedar, hemlock, poplar, maple, may be selected, and it is only necessary to discard such worthless specimens as bass wood. With respect to the scantlings, it is the custom to specify, as a matter of economy, that payment will be only made for sizes up to 15 inches square. The biggest balks are chosen for the bottom of the crib, and the others are made to work in, all the timbers being axed or sawn to the proper dimensions.

The cribs in the Lachine canal (Plate 13, Figs. 1 and 2) are at least 30 feet in length, and 15 or 30 feet wide, according to their position in the pier. The side and end timbers are 12 inches square, and are laid close on both faces of the crib. They are joined to each other at the angles by double-bevelled dovetails (Fig. 3). The cribs are strengthened by transverse and longitudinal ties, each of which extends over the full width or length of the crib, and their ends are dovetailed into the timbers above and below them. They are 14-inch timbers, flattened on two

[1] Part of a communication, descriptive of "The St. Lawrence Navigation and Canal Construction," to be dealt with separately.—SEC. INST. C.E.

sides to a thickness of 10 inches, and the cross-ties are laid 10 feet apart. As regards the longitudinal ties, it is usual to build a simple vertical centre tier in cribs up to 20 feet in width, two vertical tiers equally distributed in cribs from 20 to 30 feet wide, and so on. At times, however, the longitudinals are spaced 3, 4, or 5, &c., feet apart, the distances between them depending on the nature of the stresses to which the cribs may be subjected.

The framing is further secured by $\frac{5}{8}$-inch rag-bolts, 12 inches long, through the corner dovetails in each course, and by $\frac{7}{8}$-inch rag-bolts, 24 inches long, through the heads of each tie. The longitudinals are also checked into the cross-ties, and fastened to them by 2-inch white oak trenails, 16 inches long. Three ranges of 4-inch plank binders, 10 inches wide, are fixed to the inside of each face of a crib by means of $\frac{5}{8}$-inch spikes 10 inches long. Thus there are six ranges in all, one being placed at each angle, and one at the centre of each face.

The ballast floor consists of timbers flattened on two sides to a thickness of 10 inches; they are spaced from 18 inches to 24 inches apart, and rest on the first or second course of the side timbers, to which each piece is united by a $\frac{3}{4}$-inch rag-bolt, 18 inches long. The floor is often supported by one or more longitudinals, according to the width of the crib; these are dovetailed into and secured to the end timbers. The side timbers of the floor are usually square.

The crib is generally built in shallow water, then towed to its proposed site, and moored in position ready for sinking. It must rest uniformly and evenly on its bed, and for this reason careful soundings have to be taken very near one another; it is necessary to remove all obstructions and inequalities, or else to give to the bottom of the crib such a contour as will enable it to fit the bed. A strong platform is laid on the crib, and heavy stones are heaped upon it, until it sinks in place, when it is immediately filled with closely-packed, moderately sized, and approved stones. Provision should be made for any settling that may take place, and wedge-like portions are to be cut away or added, as required, so that finally all the lines may be true and regular.

In a type of crib which has been successfully introduced by Mr. John Kennedy, M. Inst. C.E., the Harbour Engineer of Montreal, a somewhat different construction has been adopted. These cribs were originally made about 40 feet long, but it is now usual to build them in lengths varying from 100 to 120 feet, as the timbers work in better, and the cost is thus reduced. Taking the case of a crib for a depth of 24 feet of water, it is 23 feet

wide at the bottom and 15 feet 6 inches wide at the top, which is 9 feet 6 inches above low-water line; its total height is therefore 33 feet 6 inches. The face has a batter of about 1 in 5, and is close-jointed; the back is plumb to low-water line, and is drawn in above this line to the required width. The back and ends are open work, the spaces between the timbers depending upon the different courses of ties. Up to low-water line, or perhaps within one course of such line, the timber worked into the crib is chiefly hemlock, which is the best of the cheaper kinds; but any good and sound wood may be used, excepting bass. The remaining height of 9 feet 6 inches is built of approved white pine, and is faced with pine or tamarac planking, 3 or 4 inches thick. The ballast floor is carried by ten flattened cross-ties, spaced from 6 to 8 feet apart, dovetailed into the walls, and checked into the longitudinals beneath. Five rows of longitudinals, in addition to those under the walls, extend along the bottom of the crib, so as to form a good bearing surface upon the dredged bed, and prevent the crib from being pushed forward by the pressure of the earth-filling in the rear. The floor is generally made of inferior timber and cuttings, laid with open joints. The finer ingredients of the ballasting can thus run through, fill up the space below, and form as solid a union as is practicable, between the natural soil and the crib-filling. After the crib has been sunk in place by suitably loading it on the top, ordinary river dredgings, of any kind save running sand, very soft clay, &c., are dumped into it; preference, however, is given to stones, gravel, boulder clay, shale, &c., especially towards the bottom. When the site of the crib is uneven or bad, or if there is reason to fear that the ballast floor might partially settle and leave an opening in the front, large stones are first filled in, and then smaller sizes, so as to close up any breaks that might occur, and secure the finer material above.

The cribs are separate up to within about 12 inches of low-water line; but above this the timber work is built in continuous courses, and is finally closed in with hemlock or tamarac planks 4 inches thick. Tamarac is the stronger and more durable wood; but either hemlock or pine is cheaper, and is amply sufficient in every respect for both covering and facing. Formerly it was the practice to fix along the cribs, both front and back, heavy oak coping pieces; these, however, were at least four times as expensive as smaller tamarac copings, while the latter have enough strength and durability to meet all requirements. Iron vertical and waling straps were also used to bind together the front coping

and facing; but they caused the rapid decay of the timber adjoining them, and have consequently been discarded.

The cost of one of these cribs, in place, in a depth of 24 feet of water, varies from £22 to £24 per lineal foot, exclusive of the cost of filling. The corresponding cost of a crib 19 feet 6 inches high, *i.e.*, for a 10-feet depth of water, varies from £19 to £20 per lineal foot.

The inside and the rear of the cribs are filled with river dredgings, brought to the required site on flat-deck scows. The dredgings are there handled by a simple form of "clam-shells," worked by floating steam derricks. The cost of handling chiefly depends upon the nature of the dredgings, and ranges from 5 to 20 cents. per cubic yard.

Many cribs are constructed without ballast floors, in which case the ties, both transverse and longitudinal, are built in close-jointed vertical tiers, so as to form a number of rectangular boxes. These boxes are filled with suitable stones, which are pressed into the sides, and hold the crib in position. A cribwork pier is easily ripped up and removed by an ordinary spoon dredge. The life of the portion of a crib below water, as already stated, is practically everlasting; but the life of the part above water varies exceedingly. Recently it was found necessary to remove, for repairs, a crib which had been in place more than twenty-three years. When the crib was uncovered the whole of the timbers up to low-water level were discovered to be perfectly good and sound, while above this level there were only four courses which required to be replaced. This rather unusual longevity may be thus accounted for:—During the winter the wharves are totally submerged; in the spring the ice disappears, and the water falls a little below the coping; then comes down the North water and almost submerges the wharves again; after this the river gradually lowers, and reaches its lowest level about October; it rises again in December. The upper portion of a crib is therefore dry during from two to five months of the year only.

In another example of cribwork, executed under rather exceptional conditions, the cribs were built in the construction of a dam at the Carillon Rapids, on the Ottawa River. They rest on a flat ledge of rock extending across the rapids, and are secured to it by chisel-pointed wrought-iron bolts $1\frac{1}{2}$ inch in diameter. Holes $1\frac{1}{2}$ inch in diameter, and from 12 to 18 inches in depth, were drilled into the rock and filled with pine plugs; into these were driven the bolts, numbering four on each side and three at the upper end. Each crib is 46 feet wide, and on an average 20 feet in

length. The side and end timbers are 12 inches square and 8 inches apart; the distance between the ties is 8 feet, except in the case of the ties immediately above the bottom course, which are laid about 4 feet 2 inches from centre to centre, so as to form a ballast floor. All the timbers are jointed and dovetailed, as already described, and the framing is further strengthened by $\frac{3}{4}$-inch rag-bolts through the corners and heads of the ties; the corner bolts are 16 inches and the head bolts 26 inches long. The part of the structure above water is close sheeted with tamarac planks 4 inches thick, which are fastened to the crib timbers by 8-inch pressed spikes; the lower ends of the planks are cut to fit the rock contour. The details of the cost of this cribwork, when completed, were :—

	$	
Timbers 12 inches square in section. . .	0·17	per lineal foot.
4-inch tamarac planking	0·10	„ superficial foot.
Stone filling	0·55	„ cubic yard.
Gravel above crib	0·50	„ „
Wrought iron in rag, fox, or screw-bolts .	0·14	„ lb.
Drilling holes from $1\frac{1}{2}$ inch to $2\frac{1}{4}$ inches in diameter	1·50	„ lineal foot.

Plate 13 has been prepared from one of the twelve drawings which accompanied the original communication.

(*Paper No. 1743.*)

"The Monte Penna Wire Ropeway."

By WILLIAM PATRICK CHURCHWARD, Assoc. M. Inst. C.E.

THIS line has been constructed for the Monte Penna Forest Company, Limited, which possesses an extensive portion of beech-wood forest land surrounding the Monte Penna, one of the highest points of the Apennines, 18½ miles N.N.E. of the town of Chiavari, Italy. Its object is to convey timber, and other produce, as charcoal, &c., from a point at the base of the forest to the small village of Santa Maria del Taro, at which place the Company has erected a saw-mill and other works. Communication between Santa Maria and Chiavari is opened by road.

The ropeway was constructed by the Author from the designs of Mr. W. T. H. Carrington, Assoc. M. Inst. C.E., and is now working satisfactorily. It consists of a double line of "fixed" ropeway, *i.e.*, a down and an up line, upon which the carriers, or hangers, are supported, and are drawn by an endless hauling rope, which is operated by machinery from a turbine that supplies power to the saw-mill. The down, or heavy-load line, is a steel-wire rope, 3¾ inches in circumference, whose breaking strain is 42 tons. The up, or light-load line, is a steel rope, 3 inches in circumference, with a breaking strain of 25 tons; and the hauling rope is a plough steel rope, 1½ inch in circumference, with a breaking strain of from 8 to 9 tons.

Plate 14, Fig. 1, shows a section of the line which is 2,854 yards in length, and in that distance the ropes are supported at twelve points, the spans unsupported varying in length from 31 to 743 yards. Figs. 2 and 3 give a side and front elevation of a 23-feet "post," or rope support, with a travelling carrier, or "hanger," to show the mode of transport. At each end of the line suitable stations are erected, details of which are given in plan and elevation (Figs. 4, 5, 6, and 7). The lower, or Santa Maria terminus (Figs. 4 and 5), is erected on a slope close to the saw-mill. The upper, or Carignone terminus (Figs. 6 and 7), is situated on an exposed mountain ridge, from which a road leads into the forest. The line between is perfectly straight.

The fixed ropes are kept at the required tension by box-weights,

suspended at the Carignone terminus to a strong wooden framework, and at the Santa Maria terminus in wells excavated for the purpose. The hauling rope passes round a horizontal drum, with brake-gear attached at the upper terminus, and round vertical driving and brake-drum gear, guide wheels, and horizontal slide drum, &c., at the lower terminus. The horizontal slide drum regulates the tension of the hauling rope to the required tractive force. The line is driven at a speed of 4 miles per hour, and can be set in motion or stopped by the person in charge in the station-house of the Santa Maria terminus, from which communication is carried on with Carignone by an electric bell telegraph.

Each load is placed on the line 475 yards apart, at which distance rings are spliced into the hauling rope, through which a shackle is passed to connect it to the ear-piece of the carrier head. There are six carriers on the down line, and six on the up line, one of which on each line is arranged to arrive at the stations simultaneously. On arrival they are disconnected, and the hauling rope is moved on until the rings are in position to attach on the opposite side. Here another carrier is connected, and the line is again set in motion. The carriers weigh 5 cwt. each, and the loads vary from 6 cwt. to 20 cwt., according to the sizes of timber, &c. All necessaries for the workmen in the forest are sent up on the light-load line in weights up to 1½ cwt.

This ropeway has been constructed in a substantial manner, most of the timber for stations, posts, &c., being injected with a solution of sulphate of copper to retard decay. The total cost of the line was £4,000, including the construction of the short inclined railway at the Santa Maria terminus, telegraph, terminal arrangements, &c. It is capable of conveying eight loads per hour, or per day of ten hours as many as two hundred logs of timber, 10 feet long by 15 inches in diameter; or 320 sacks, = 25 tons, of charcoal, at a working cost of £4 per diem, nearly 50 per cent. of this sum being included for wear and tear of ropes and machinery.

The communication is accompanied by three drawings, two maps of the district, and one tracing, from which Plate 14 has been reduced and engraved.

(*Paper No. 1752.*)

"On the Calculation of Dimensions as Depending on the Ultimate Working Strength of Materials."

By Dr. J. WEYRAUCH, Professor at the Polytechnicum, Stuttgart.

Translated by GEORGE RUDOLPH BODMER, Assoc. M. Inst. C.E.

I. LEADING POINTS OF VIEW.

IN the choice of the admissible stresses for iron and steel either the ultimate strength or the limit of elasticity has been the starting-point. The new method aimed at by German engineers depends on the ultimate strength only. There are no longer any representatives of the other school among German writers, although the stress produced by the working load is always kept below the ordinary limit of elasticity. Formerly the ultimate working strength[1] a (*Arbeitsfestigkeit*) was assumed as constant, so that a bar which had once sustained a certain static load, could also support it under a quicker application and with an indefinite number of repetitions. The question is, whether in the present state of knowledge a may not be expressed with smaller errors by a formula. If a formula is decided upon, the general algebraical expression for it—

$$a = f(x\,y\,\ldots), \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

denoting that a is some function of $x, y, \ldots$ takes the place of the constant working strength

$$a = C,$$

where C is some constant used in the earlier method of determining dimensions. Various general formulæ for a have been proposed in Germany. Whichever of them be adopted the choice of a numerical expression may turn out to be different according to the material and experience of the individual, just as until

[1] Or resistance to fracture under the straining action produced by the working conditions of the material. See definition in IV.—ED.

now different values of a = C have been in use. As, however, under the most favourable circumstances, no values universally correct can result from a formula, having regard to all unforeseen and uncontrollable influences (faulty material, unintentional distribution of stress, rust, shocks, &c.), so now, as formerly, factors of safety must be used, the choice of which depends upon the object of the structure and the judgment of the designer. In this way, even with the same numerical value of the working strength a, different values are obtained for the admissible stress, just as when for the same assumed value of a, say 3,500 kilogrammes per square centimètre, different engineers chose 600, 700, and 800 as admissible stress. When the admissible stress per unit of area has been fixed, the necessary effective area of section is made, as hitherto,

$$F = \frac{\max B}{b}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

max B being understood to mean the numerical value of the absolute maximum load.

The desired improvement (*Neuerung*) requires, as compared with the old method, only an altered choice of b.

II. Wöhler's Law.

That under a frequent alternation of tension and compression a bar does not sustain the same stress as under a static load has probably long been everywhere appreciated. The same remark applies to variable stress, whether tensile alone or only compressive. Before Wöhler's time account had been already frequently taken of this in calculations.[1]

The formulæ given by German engineers aim mainly at substituting, instead of a mere guess (*Schätzung*) at the most suitable stress on every occasion, a certain consistency or regularity. From the nature of the case no far-reaching accuracy can be attempted, but only a limitation of previous errors. Former rules depended more upon "feeling" than on definite experimental results. Still it was considered that they were to be preferred to the assumption

[1] *Vide* under X., and Weyrauch, "Strength and Determination of the Dimensions of Structures of Iron and Steel." Translated by Prof. Jay du Bois, New York, 1877, Wiley, pp. 2 and 159.

of a constant working strength. Thus arose the recognition accorded to the experiments undertaken by Wöhler between the years 1859–70 on behalf of the Prussian Ministry of Commerce, in order to determine the capability of materials for resistance to repeated and alternating straining actions. A complete account of these experiments is found in Wöhler's publications,[1] and Spangenberg, on continuing the experiments, confirmed his results.[2] In earlier experiments on the strength of materials, it was ascertained by a gradually increasing load what tensile, compressive or shearing stress, once for all, could break a bar whose sectional area was unity, and this quantity t was called the tensile, compressive, shearing or breaking strength of the material. By Wöhler's experiments it was shown, that, though a given stress t can break the piece by a single application, smaller stresses can produce fracture if they are often enough repeated.

Wöhler concluded from this, that the change in the grouping of the molecules, which is produced by the varying stress, acts unfavourably on the resistance of the material. In that case fracture must take place more readily the greater the differences in the alternate stresses, because with these the change of position of the molecules also increases. With reference to these considerations, and on the basis of his experimental results, Wöhler enunciated the following law:—

The fracture of a material may be effected not only by a static load producing stress equal to t, but also by often repeated vibrations producing stresses of which no one attains t. The differences of stress in so far affect the cohesion, that, as they increase, the minimum stress capable of causing fracture decreases. With the stress t the material is broken by a single application. Smaller stresses than t can produce fracture by many repetitions. The smaller the stress, the more numerous the repetitions necessary for fracture. Conversely, the stress may be greater, the fewer repetitions it is intended to make. According to these principles, in judging of the degree of safety of a structure, much depends on whether it is only expected to remain in use for a certain time, or whether it is intended for permanent durability.

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[1] Wöhler in Zeitschrift für Bauwesen, 1860, 1863, 1866, 1870, *passim*.

[2] Spangenberg in Zeitschrift für Bauwesen, 1874, 1875, and Minutes of Proceedings Inst. C.E., vol. lx., p. 415.

III. Remarks on Wöhler's Law.

That, since the experiments of Fairbairn,[1] Wöhler, and Spangenberg, apart from earlier experience, the ultimate working strength a can no longer be considered constant, will scarcely be disputed. It is another question whether Wöhler's law forms a reliable basis for judgment. In Germany this has been pretty generally assumed, as the numerous methods of determining dimensions based upon it testify, of which Gerber's[2] has been adopted by the Bavarian Government.

The Launhardt-Weyrauch method, which has probably found the most general acceptance, also starts from Wöhler's law. If this law is recognised, it must still be admitted that further definition of it is desirable.

In Wöhler's experiments the load was applied at very brief intervals; nevertheless, the stresses required a certain time to attain their full magnitude; but there is no question of actual blows (*Stösse*). Now what influences are respectively and separately due to the frequency of the application, the rate of increase, and the duration of the individual straining actions? The two latter influences have been neglected under the assumption of a constant ultimate working strength; in bridge design the first is ordinarily viewed too unfavourably, if considered in the light of Wöhler's results.

That the law in question is not absolutely essential to the explanation of a variable strength has been lately shown by Lippold.[3] He starts from the following law: "To break a bar a certain amount of mechanical work is necessary, and this can be accumulated in the material at once just as well as by repeated loads. These loads must, however, be applied instantaneously, or so rapidly that vibrations arise." It is essential to this view, that only by means of vibrations can equal strain (*i.e.*, proportionate extension, or proportionate shortening, as the case may be), and with it equal stress and equal work, be attained by a load below that which produces t as by t itself, while less weight is attached to the repetitions of the straining action. Lippold arrives at formulæ for a, according to which the strength varies in the same manner as when based on Wöhler's law.

It is doubtless possible that in time, through speculation and

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[1] *Vide* Phil. Trans. 1864, p. 311, "Useful Information for Engineers," 3rd Series, 1866.

[2] Gerber in Zeitschrift des Bayerischen Arch. und Ing.-Vereins, 1874.

[3] *Vide* Organ für die Fortschritte des Eisenbahnwesens, 1879.

experiment, safe foundations for a correct theory of properties relating to strength will be reached. The Author, however, is not satisfied to rest contented till then with the certainly false assumption of constant strength. Smaller errors and greater safety for structures can already be attained through the results of Wöhler's experiments.

IV. On the Strength of Materials.

To start from Wöhler's law, regarding it as purely empirical:—

The words "often repeated" (II.) may be suppressed, and it may be left an open question what influences are concerned in the fracture of the piece. If, for the method hitherto used in determining dimensions, a new method is to be substituted, the latter must be sufficiently well founded, simple in its application, and in conformity with experience. At the same time it may be remembered that it is not a question of ingenious laws of unattainable accuracy, but of a useful guide for practical purposes. In the first place it has to be determined by a formula how the ultimate working strength a varies with the difference between successive stresses.

In developing or judging of this formula the results of experiment should find application, but if possible only such as have been obtained with the same class of material and under exactly the same circumstances; for only in this way can the effects of varied loading be ascertained independently of foreign influences.

The variable resistance to fracture, a, is in Germany called, according to Launhardt, "ultimate working strength" (*Arbeitsfestigkeit*). The terms, too, of tensile strength, compressive strength, shearing strength, &c., are to be taken in a wider sense than hitherto, to mean the ultimate working strength a for tension, compression, shearing, &c. Three special values of the ultimate working strength are of particular interest.

I. The amount per unit of section of the resistance to fracture by a single application of a statical, or at any rate very gradually applied load, which hitherto has been alone considered, may be called "statical breaking strength," t, (*Tragfestigkeit*).

II. If, after every application of the load, the bar reverts to its original unloaded condition, and if all stresses are in the same sense,[1] *e.g.* tension, compression, or shearing in one sense only, the

[1] "Direction" of a force, or a stress, is any line parallel to its line of action, and may be regarded indifferently as from left to right or right to left. "Sense" distinguishes between these two alternatives. Thus if a force is exerted from

greatest stress which can be sustained under the specified number of repetitions is called, according to Launhardt, the "primitive strength," u, (*Ursprungsfestigkeit*).

III. Finally, for strength as regards alternating stresses of equal intensity in opposite senses, *i.e.* for tension and compression, or for shearing in opposite senses, these being due to vibrations taking place about the original position of unstrained equilibrium, the Author has introduced the term "vibration-strength," s, (*Schwingungsfestigkeit*).

Of course the statical breaking strength t and the primitive strength u apply to either tension, compression, or shearing. If it be assumed, with Wöhler, that repetitions of the straining action are essentially dangerous to the material, u and s must be less the more repetitions are intended, and hence minima for a bridge which is to last for ever. In giving numerical values in the sequel the latter case is contemplated.

V. Launhardt's Formula.

Suppose a bar whose sectional area is unity to experience stresses in the same sense which vary between the maximum a and the minimum a'. The difference of stress is here

$$d = a - a',$$

and

$$a = d + a' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

According to Wöhler's law a diminishes as d increases. From (3). and the definitions of the statical breaking strength t and primitive strength u, the two limits of value for a are

$$\text{for } a' = 0, \quad a = d = u,$$
$$\text{,, } d = 0, \quad a = a' = t.$$

As according to Wöhler a should be a function of d,

$$a = f d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where f is at present an unknown multiplier. It is known, however, that

$$\text{for } d = 0 \text{ since } a = t, \quad f = \infty,$$
$$\text{,, } d = u \quad \text{,,} \quad a = d, \quad f = 1.$$

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right to left it is exerted in one sense; if from left to right, in the opposite sense. The two opposite senses may, if required, be distinguished as positive sense and negative sense. This use of "sense" is universal among French writers on mechanics, and helps precision of statement.—Ed.

For intermediate values of a the variation of f must be determined by considering experimental results obtained under circumstances as nearly as possible identical.

The coefficient chosen by Launhardt

$$f = \frac{t-u}{t-a} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

corresponds to the best of these results, and fulfils the imposed conditions. Hence by (4)

$$a = \frac{t-u}{t-a} d = \frac{t-u}{t-a} (a - a');$$

and therefore, reducing,

$$a = u\left(1 + \frac{t-u}{u} \cdot \frac{a'}{a}\right). \quad . \quad . \quad . \quad . \quad . \quad (6)$$

If B denotes the total load on a bar of any section, alternating between maximum and minimum values, the ratio of the less to the greater limit of stress is

$$\phi = \frac{\min B}{\max B} = \frac{a'}{a}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

so that

$$a = u\left(1 + \frac{t-u}{u} \cdot \frac{\min B}{\max B}\right). \quad . \quad . \quad . \quad (8)$$

This is Launhardt's formula.[1] It is applicable when a member of a structure is always subjected solely to tension, solely to compression, or solely to shearing stress in one sense, the values of t and u only, the statical breaking strength and the primitive strength for tension, compression, or shearing, as the case may be, having to be substituted.

VI. Remarks on Launhardt's Formula.

In order to ascertain whether Launhardt's choice of the coefficient f is applicable also to intermediate cases, equation (6) is to be solved for a, giving

$$a = \frac{u}{2} + \sqrt{\frac{u^2}{4} + (t-u)\,a'}, \quad . \quad . \quad . \quad (9)$$

where the + sign must be chosen before the radical, because a

[1] *Vide* Zeitsch. des Arch. und Ing.-Vereins zu Hannover, 1873.

must be positive and not less than u; since, as defined in V., its least value is u, and greatest t.

The most complete results are those which Wöhler obtained[1] in making bending experiments with unhardened Krupp spring-steel. This material showed for a statical breaking strength of about 1,100 centners per square inch (Rhenish), a primitive strength of $u = 500$ centners per square inch; whence from equation (9) the ultimate working strength in this case must be

$$a = 250 + \sqrt{62{,}500 + 600\,a'}.$$

There follows for . . . . $a' =$	0	250	400	600	1,100
By Launhardt's equation . . $a =$	500	711	800	900	1,100
„ Wöhler's experiments. . $a =$	500	700	800	900	1,100

For unhardened spring-steel from Mayr of Werben the experiments also give $u = 500$, $t = 1{,}100$; while for hardened Krupp spring-steel, the lowest values are $u = 600$, and $t = 1{,}200$.

Wöhler obtained from bending experiments with iron for axles made by the Phœnix Company $t = 550$, $u = 300$; whence follows

$$a = 150 + \sqrt{12{,}500 + 300\,a'}.$$

For example if $a' = 240$, equation (9) gives for the ultimate working strength $a = 440$; which agrees exactly with the value given by his tension experiments.

Unfortunately only a few among Wöhler's experiments give t, u, s, and intermediate values of a. Considering, however, that absolutely exact laws for constructive materials will certainly never result from experiments, that even in brands of iron acknowledged to be good, differences in the statical breaking strength t of as much as 40 per cent. occur, and that it is merely a question of finding a substitute for the still more rough and incorrect assumption of a constant a, even the preceding might suffice for practical purposes until more facts are accumulated.

Launhardt's formula (4) is the expression of Wöhler's law. By the latter the limits of value for f are also determined. In the

[1] Wöhler "Über die Festigkeitsversuche mit Eisen und Stahl;" Berlin Zeitschrift für Bauwesen, 1870, pp. 7 and 14 of the reprint. As it is merely a question of comparison, the Author retains Wöhler's original values and denominations.

first instance the choice of the interpolation formula for f is arbitrary. Nevertheless, this choice appears to be well justified by the only experiments of Wöhler's suited for comparison. Neither results from other sources, nor experience, nor practical feeling are against it. Even for more exact determinations than those under consideration such an approximation ought to be considered satisfactory. To the Author's mind it would appear sufficient if the deviations of the real values of a from those given by the formula did not exceed the deviations from one another of real values of a in good and commonly used materials.

VII. Weyrauch's Formula.

Suppose a bar of unit sectional area subjected to alternating straining actions in opposite senses. If then a be the numerical value of the greater, a' that of the lesser limit of stress, the difference of stress is $d = a + a'$, and therefore

$$a = d - a' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

According to Wöhler, a diminishes as d increases, and is a function of d, so that as in V.,

$$a = f d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10\text{A})$$

Since, by the definitions of the primitive strength u, and the vibration strength s in IV.,

$$\text{for } a' = 0, \quad a = u = d,$$
$$\text{,, } a' = s, \quad a = s = \tfrac{1}{2} d,$$

therefore the following conditions must be fulfilled—

$$\text{for } a = u, \quad f = 1,$$
$$\text{,, } a = s, \quad f = \tfrac{1}{2}.$$

Intermediate cases should depend on the results of experiment which, however, at present do not exist. In the meantime the two conditions just mentioned are fulfilled by the coefficient

$$f = \frac{u - s}{2u - s - a}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

hence, from (10A),

$$a = \frac{u - s}{2u - s - a} d = \frac{u - s}{2u - s - a} (a + a'),$$

and therefore

$$a = u\left(1 - \frac{u - s}{u} \cdot \frac{a'}{a}\right) \quad . \quad . \quad . \quad . \quad . \quad (12)$$

If now, for a bar of any section, max B is the numerical value of the absolutely greatest load, max B′ the numerical value of the greatest load in the opposite sense, distinguished from the other as negative, then the ratio of the less to the greater limit of stress is

$$\phi = -\frac{\max B'}{\max B} = -\frac{a'}{a}; \quad . \quad . \quad . \quad . \quad . \quad (13)$$

whence from (12)

$$a = u\left(1 - \frac{u - s}{u} \cdot \frac{\max B'}{\max B}\right) \quad . \quad . \quad . \quad (14)$$

This is Weyrauch's formula. It is always to be applied in those cases where a member of a structure is subject to stresses alternating between tension and compression, or between shearing actions in opposite senses.. By u and a are to be understood, respectively, the primitive strength and ultimate working strength for the numerically greater of the two alternate stresses if they differ in amount.

VIII. Remarks on Weyrauch's Formula.

If equation (12) be solved for a,

$$a = \frac{u}{2} + \sqrt{\frac{u^2}{4} - (u - s)\,a'} \quad . \quad . \quad . \quad (15)$$

In this formula, from (12),

$$(u - s)\,a' = au - a^2.$$

The maximum of this expression is found by differentiation with respect to a, thus:—

$$\frac{d\,[(u - s)\,a']}{da} = u - 2a = 0,$$

to occur when $a = \frac{1}{2}u$, and the maximum value of

$$(u - s)\,a' = au - a^2 = \frac{u^2}{4}.$$

Hence the expression under the radical in equation (15) can never

become imaginary, and this refutes an objection in "Engineering" (vol. xxix., pp. 304, 341).

Wöhler found for alternations of tension and compression for "Phœnix" iron

$$u = 2{,}190,\ s = 1{,}170;$$

for Krupp cast steel for axles

$$u = 3{,}510,\ s = 2{,}050;$$

for shearing stress in opposite senses with the same material

$$u = 2{,}780,\ s = 1{,}610$$

centners per square inch (Rhenish). It is a decided defect that the choice of the coefficient f for the intermediate stages cannot for the present be checked by experiment. This is of course true of all empirical formulæ, which may be constructed on Wöhler's data for stresses in opposite senses. When, however, it is admitted that s and u are not equal, or in other words, that the same ultimate working stress cannot apply in cases of alternation between tension and compression that applies to intermittent tension alone, it becomes evident that an interpolation formula must be adopted. The Author considered that it ought to be built up by reasoning similar to Launhardt's, and hence in Germany the formulæ,

$$a = u\left(1 + \frac{t-u}{u}\phi\right) \text{ for positive } \phi \quad . \quad (16)$$

$$a = u\left(1 + \frac{u-s}{u}\phi\right) \text{ „ negative } \phi, \quad . \quad (17)$$

are always applied side by side. In both (16) and (17) t, u, and s are numerical values without sign [+ or −], while the ratio ϕ of the least to the greatest limit of stress is positive or negative according as the extreme alternate stresses are in the same or different senses. The results which are obtained by formula (17) do not at any rate contradict practical feeling or assumptions hitherto customary (*vide* X.)

IX. Admissible Stress for Iron.

In determining the numerical values of the admissible stress per unit of area, Wöhler's experimental results must be applied. At the same time every illusion as to the universal applicability of the latter is to be put aside; just as formerly a new series of experiments on the statical breaking strength t was accepted

without their results being henceforth exclusively used. If, for instance, in such cases a statical breaking strength of $t = 3{,}870$ kilogrammes per square centimètre resulted, 3,500, perhaps, was taken as a low value; so, if not still more cautiously, similar judgment must be exercised in the choice of a. Beyond this, the help of factors of safety was always resorted to, and this must still be so in the future. In the following determinations particular reference is made to iron bridges. For simple compression, in accordance with the usual practice, the same limiting stresses as for tension are adopted.

Alternating stresses, either exclusively tensile, or exclusively compressive.—In what follows the numerical intensities of stress are expressed in kilogrammes per square centimètre. With iron for axles of the "Phœnix" Company, bending experiments of Wöhler's gave $t = 4{,}020$, $u = 2{,}190$; whence $\frac{t-u}{u} = \frac{5}{6}$; and by (16)

$$a = u\left(1 + \frac{t-u}{u}\phi\right) = 2{,}190\,(1 + \frac{5}{6}\phi).$$

If the formula is to afford the desired security for any tensile or compressive stress, a start must always be made from the most unfavourable case of this stress. For the same iron, with the direct application of tensile stress, $u = 2{,}190$ also; but $t = 3{,}290$ only. Therefore take

$$\frac{t-u}{u} = \frac{3{,}290 - 2{,}190}{2{,}190} = \frac{1}{2}, \text{ very approximately;}$$

and suppose the ultimate working strength be further reduced by rounding off the value of u on the side of safety, to

$$a = 2{,}100\,(1 + \frac{1}{2}\phi).$$

If $\frac{1}{3}$ is chosen as a suitable factor of safety, the admissible stress per square centimètre then becomes

$$b = 700\left(1 + \frac{\phi}{2}\right) \quad \ldots\ldots\ldots \quad (18)$$

Alternation between tensile and compressive stresses.—For the Phœnix iron above-mentioned Wöhler found $u = 2{,}190$, $s = 1{,}170$; hence in this case $\frac{u-s}{u} = \frac{7}{15}$, and by (17),

$$a = u\left(1 + \frac{u-s}{u}\phi\right) = 2{,}190\,(1 + \frac{7}{15}\phi).$$

Rounding off these values on the safe side by diminishing 2,190 to 2,100 and increasing $\frac{7}{15}$ to $\frac{1}{2}$, since ϕ is negative, there results

$$a = 2{,}100\ (1 + \tfrac{1}{2}\phi),$$

whence, with the factor of safety $\frac{1}{3}$ the admissible stress per square centimètre becomes

$$b = 700\left(1 + \frac{\phi}{2}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

Shearing stresses.—In most practical cases a and b for shearing stresses may be made $\frac{4}{5}$ of what they would be with the same ratio of stress ϕ for tension and compression.[1] Therefore, generally,

$$b = 560\left(1 + \frac{\phi}{2}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

where ϕ is positive or negative, according as the alternating limits of stress are in the same or in opposite senses.

X. Remarks on the Choice of b.

It has been shown in the above that the stress per square centimètre may be generally expressed—

$$\text{for positive } \phi, \text{ by } b = v\,(1 + m\,\phi) \quad . \quad . \quad (21)$$
$$\text{,, negative } \phi \text{ ,, } b = v\,(1 + n\,\phi) \quad . \quad . \quad (22)$$

where v, m, n, are constants depending on the nature of the material and sense of stress, ϕ the ratio of the less to the greater limiting stress. When the admissible stress per unit of area has been fixed, the necessary net sectional area is found by

$$F = \frac{\max B}{b}.$$

For iron, in particular, as explained in IX., there may be assumed for tension and compression $v = 700$, $m = n = \frac{1}{2}$, so that very simply,

$$\left.\begin{aligned} b &= 700\left(1 + \tfrac{1}{2}\right), \\ F &= \frac{\max B}{700\left(1 + \frac{\phi}{2}\right)} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (23)$$

[1] *Vide* "Strength and Determination of the dimensions of Structures of Iron and Steel," by Dr. P. J. J. Weyrauch, pp. 81–88 *ante*.

By this threefold safety is attained if

$$t = 3{,}150,\ u = 2{,}100,\ s = 1{,}050.$$

Smaller values of strength for bridges than these figures indicate are certainly not necessary, and have not been hitherto customary. Notwithstanding this, as has already been remarked in I., these values can have no universal application, and should they be thought too high for the material and the purpose, the following may perhaps be suitable: $v = 640$, $m = n = \frac{1}{2}$; whence

$$\left.\begin{aligned} b &= 640\left(1 + \frac{\phi}{2}\right), \\ F &\leqq \frac{\max B}{640\left(1 + \frac{\phi}{2}\right)} \end{aligned}\right\} \quad \ldots\ldots\ (24)$$

Different values also may be assigned to m and n; for steel, for instance, different values cannot be avoided.[1]

Exception[2] has been taken to the fraction $\frac{1}{2}$. With equal justice the choice of $b = 700$ might have been considered dubious, and 687 preferred. It may suffice to answer that, in these objections, general and special facts have been confused.

When for booms of girders p is the dead load, q the total load per lineal mètre, and $\phi = \dfrac{\min B}{\max B} = \dfrac{p}{q}$; then

$$b = v\left(1 + m\frac{p}{q}\right) = 700\left(1 + \frac{p}{2q}\right); \quad (25)$$

these latter numerical values for wrought iron being according to IX.

With the numerical values assumed for b, the admissible stresses for a static load, for alternations between tension and an unloaded condition, and for alternations between tension and compression of equal amount, would stand in the ratio 3 : 2 : 1. The Author is given to understand that this ratio has been adopted as a matter of experience in the practical construction of machinery, independently of Wöhler.

Launhardt quotes an older method of American engineers. According to this method, if tension alone alternating from 0 to 700

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[1] *Vide* Weyrauch "Strength and Determination," &c., pp. 60–68.

[2] *Vide* "Engineering," vol. xxix., p. 263.

kilogrammes per square centimètre were admissible, for alternations of tension and compression the following formula was used—

$$F = \frac{\max B + \max B'}{700} \quad . \quad . \quad . \quad . \quad . \quad (26)$$

whence, if $\phi = \frac{\max B'}{\max B}$,

$$b = \frac{\max B}{F} = \frac{700}{1 + \phi} \quad . \quad . \quad . \quad . \quad . \quad (27)$$

Comparing this with (23):—

For ϕ . . .	=	0,	$\frac{1}{4}$,	$\frac{1}{2}$,	$\frac{3}{4}$,	1,
according to formula (27) b =		700,	560,	467,	400,	350,
„ „ „ (23) b =		700,	612,	525,	437,	350.

Wöhler concluded from his own experiments that the following values were admissible for iron structures of unlimited duration:

For alternations between tension or compression only, and an unloaded condition, $b = 1{,}100$ (above, 700), for alternations between equal tensile and compressive stresses, $b = 580$ (above, 350).

Previous to his becoming acquainted with the Weyrauch formula, Launhardt recommended a provisional adoption of (26.)

XI. On the Liability to Buckling.

In the preceding demonstration, the buckling strength has not been considered.

Other methods proposed in Germany and Austria have also left this question out of consideration,[1] as it was formerly almost universally the practice in those countries to calculate even the struts of lattice bridges for simple compression only. It was sought to avoid the risk of buckling by large moments of inertia of sections, and when necessary by fixing intermediate points. Since, however, the neglect of the liability to buckling had been noticed by American reviewers, the Author first showed how it could be taken into account in the Italian edition of the work already frequently quoted. The following short demonstration may serve as a supplement to the English edition.

Of course it is not a question of improving the very defective theory of buckling of Euler and Navier, still less of reconstructing

[1] Schäffer in his modification of Gerber's method has subsequently taken it into account. Deutsche Bauzeitung, 1877.

the empirical formulæ of Rankine and Gordon. Nevertheless, the Author is so much convinced of the inaccuracy of the latter makeshifts, that it appears incredible to him how some English engineers, who remain contented with them, could raise objections on the score of inaccuracy to the formulæ given above.

According to the preceding (X), if F_d denote the requisite sectional area of a strut without liability to buckling, the stresses on which alternate between the maximum compression B_d and the minimum compression B_δ, then

$$F_d = \frac{B_d}{b} = \frac{B_d}{v\left(1 + m\frac{B_\delta}{B_d}\right)}; \quad . \quad . \quad . \quad . \quad (28)$$

and for a bar, which is strained between the maximum compression B_d and the maximum tension B_t, there follows—

$$\text{for } B_d > B_t, \quad F_d = \frac{B_d}{b} = \frac{B_d}{v\left(1 - n\frac{B_t}{B_d}\right)} \quad . \quad (29)$$

$$,, \quad B_d < B_t, \quad F_d = \frac{B_t}{b} = \frac{B_t}{v\left(1 - n\frac{B_d}{B_t}\right)} \quad . \quad (30)$$

All stresses are to be substituted here as numerical values without signs.

XII. Consideration of the Liability to Buckling.

If for any strut or pillar, l be the length, F the sectional area, I the least moment of inertia of the section for axes through its centre of gravity and lying in its plane, E the modulus of elasticity, t the statical breaking strength for simple compression only, δ a coefficient known from the theory of buckling depending on the method of securing the ends, let the following expression be introduced:—

$$\mu = \frac{F\,t\,l^2}{\delta\,E\,I} = \frac{F\,l^2}{I\,\sigma} \text{ where } \sigma = \frac{\delta E}{t} \quad . \quad . \quad (31)$$

and there results, according to the theory, as mean stress per unit of section at the moment of buckling—

$$t_k = \frac{\delta\,E\,I}{F\,l^2} = \frac{t}{\mu} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (32)$$

For the transmission of a pressure B_d there is required with a static load, without liability to buckling, a section $\frac{B_d}{t}$; with liability to buckling, a section $\frac{B_d}{t_k}$. In a sectional area F, the greatest stress per unit of area is without liability to buckling $\frac{B_d}{F}$. Let k be the hypothetical stress per unit of area obtained on the supposition that the greatest stresses implied in (28) and (32) have the same ratio as the required sectional areas. Then

$$k : \frac{B_d}{F} = \frac{B_d}{t_k} : \frac{B_d}{t}.$$

Substituting from (32) there follows—

$$k = \frac{B_d}{F} \cdot \frac{t}{t_k} = \frac{\mu B_d}{F}.$$

This stress would be that due to a force equally distributed over the whole sectional area—

$$B_k = F k = \mu B_d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (33)$$

If B_k be substituted throughout in place of B_d, the same formulæ apply as without liability to buckling. The compressive force B_d, with liability to buckling, is equivalent to a compressive force B_k without liability to buckling.

The necessary sectional area on the assumption of a liability to buckling follows from (28)–(30):

for bars under compression only

$$F = \frac{B_k}{b} = \frac{\mu B_d}{b} = \mu F_d ; \quad . \quad . \quad . \quad . \quad (34)$$

for alternations of tensile and compressive loads, B_t and B_d respectively :—

when $\mu B_d > B_t$, $F = \frac{B_k}{b} = \frac{\mu B_d}{v\left(1 - \frac{n B_t}{\mu B_d}\right)}$ . . (35)

when $\mu B_d < B_t$, $F = \frac{B_t}{b} = \frac{B_t}{v\left(1 - \frac{n \mu B_d}{B_t}\right)}$ . . (36)

XIII. Another Method of Considering the Liability to Buckling.

The formulæ (34)–(36) derived from Navier's theory of buckling are only to be used for $\mu > 1$, as for $\mu < 1$ the calculation for uniform compressive stress only by (28)–(30) leads to greater sections. Hitherto in determining dimensions many engineers have been in the habit of combining the formulæ for uniform compressive stress and buckling, so that instead of writing in the one case without liability to buckling $F\,t = B_d$ and in the other with liability to buckling $F\,t = B_k = \mu\,B_d$, they introduced, generally, according to the practice of Rankine and Gordon,

$$F\,t = (1 + \mu)\,B_d, \quad B_d = \frac{F\,t}{1 + \mu} \quad . \quad . \quad . \quad (37)$$

In an exactly corresponding manner the method of determining dimensions here under discussion may be proceeded with. Substitute, instead of in the one case B_d and in the other $\mu\,B_d$, generally, $(1 + \mu)\,B_d$; whence instead of the formulæ (28)–(30) applicable only for $\mu < 1$ and of those (34)–(36) admissible only for $\mu > 1$, the following formulæ, always applicable to bars under compression, with or without liability to buckling, appear:

for bars under compressive load only:—

$$F = (1 + \mu)\,F_d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (38)$$

for alternations of tensile and compressive loads B_t and B_d respectively:—

$$\text{if } (1 + \mu)B_d > B_t, \quad F = \frac{(1 + \mu)\,B_d}{v\left(1 - \frac{n\,B_t}{(1 + \mu)\,B_d}\right)} \quad (39)$$

$$\text{if } (1 + \mu)\,B_d < B_t, \quad F = \frac{B_t}{v\left(1 - \frac{n\,(1 + \mu)\,B_d}{B_t}\right)} \quad (40)$$

These equations resolve themselves for $\mu = 0$ into those applicable for simple compression only (28)-(30), and for μ very large as compared with 1 into the formulæ (34)–(36) derived from the theory of buckling. They give larger sections than each of the corresponding others respectively.

XIV. Ordinary Practice with Liability to Buckling.

The method pursued in determining dimensions with reference to buckling will, in most cases, be the following.

In the first place F_d is determined for simple compression only by (28)–(30), the section is provisionally arranged accordingly, μ is found by (31), and the formulæ (34)–(36) or (38)–(40) can then be applied.

The struts of bridges have usually a spread-out (*gespreizten*) section, and in most cases it will be found that $\mu < 1$, so that for those who adopt Navier's buckling theory, and therefore the formulæ (34)–(36), no liability to buckling exists, and the values of F_d remain as the final sectional areas. Those, however, who have hitherto used the empirical formulæ (37) in determining dimensions, may with equal propriety apply the new method by means of the equations (38)–(40).

The increase of section from F_d to F, rendered necessary by the liability to buckling, may in struts of bridges be usually attained by a slight strengthening of their flanges. $\frac{I}{F}$ and $\frac{I_d}{F_d}$, where I_d is the value of I for the increased section, then differ so little that another calculation of F with the more accurate μ is superfluous, the more so as the coefficient σ is in no case very reliably determined.

This coefficient would be calculated for the various methods of securing the ends of struts with reference to the values of δ corresponding to the theory of buckling from (31). At the same time the theory does not agree particularly well with experience; and, in practice, ends absolutely rigidly fixed, or perfectly free to turn round the centres of their joints, by reason of frictionless articulation, do not actually occur. For iron bars with so-called fixed ends, the Author is in the habit of making $\sigma = 24{,}000$;[1] for iron bars with both ends secured by pins (American bridges) $\sigma = 18{,}000$ has been given.[2]

For the other constants occurring in the preceding formulæ $v = 700$, $m = n = \frac{1}{2}$.

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[1] For this values from 10,000 to 36,000 are in use. With $E = 2{,}000{,}000$, and $t =$ 3,300 kils. per square centimètre, the theory gives, according to (31), $\sigma = 23{,}900$. Later American experiments (Civilingenieur, 1878, pp. 17-28) lead with the assumption of formula (37) to a mean value 22,700.

[2] Prof. Cain in Van Nostrand's Eclectic Eng. Mag., 1877, p. 458.

XV. Examples.

Considering the simplicity of the method of determining dimensions here recommended, few examples are needed.[1]

Example 1.—The stress on a bar, normal to its cross section, varies between the tension 50,000 and the tension 20,000 kilogrammes. Required the admissible stress per square centimètre and the necessary sectional area.

$$\text{By (23)} \quad b = 700\left(1 + \frac{1}{2} \cdot \frac{20{,}000}{50{,}000}\right) = 840 \text{ kilogrammes per sq. centim.}$$

$$F = \frac{50{,}000}{840} = 59{\cdot}52 \text{ square centimètres.}$$

Example 2.—The stress alternates, in a similar case, between the tension 40,000 and the compression 30,000 kilogs. The sectional area, without reference to buckling, is to be determined.

$$\text{By (23)} \qquad F = \frac{40{,}000}{700\left(1 - \frac{30{,}000}{2 \times 40{,}000}\right)} = 91{\cdot}43 \text{ sq. centimètres,}$$

where the admissible stress per square centimètre

$$b = 700\left(1 - \frac{30{,}000}{2 \times 40{,}000}\right) = 437{\cdot}5 \text{ kilogrammes.}$$

Example 3.—What limiting stress per square centimètre should be chosen for the booms of a lattice girder when the ratio of the dead weight to the greatest total load amounts to $\frac{p}{q} = \frac{1}{3{\cdot}5}$?

$$\text{By (25)} \qquad b = 700\left(1 + \frac{1}{2 \times 3{\cdot}5}\right) = 800 \text{ kilogrammes.}$$

With 640 instead of 700 it would be 745.

Example 4.—The load on a hollow cylindrical column varies between the compression $B_d = 50{,}000$ and the compression $B_\delta =$

[1] For further explanations for special structures, see Weyrauch, "Strength and Determination, &c."; on the calculation of rivet joints, the same work; on the consideration of the liability to buckling, Weyrauch, "Stabilita delle construzioni in ferro ed in acciaio"; on a special method of taking into account the shocks produced by the moving load, Zeitschr. d. Östreich. Ing. u. Arch.-Vereins, 1879.

20,000 kilogrammes. The sectional area for the length $l = 400$ centimètres is to be calculated with reference to buckling.

From (28) or (23) or Example 1, where there is no liability to buckling, $F_d = 59 \cdot 52$ square centimètres. Corresponding to this, the section is temporarily assumed as a ring of 10 centimètres outer, and 9 centimètres inner radius, whence follows $F = 59 \cdot 7$, $I = 2{,}700$ centimètre-units. Equation (31) gives—

$$\mu = \frac{59 \cdot 7 \times 400^2}{2{,}700 \times 24{,}000} = 0 \cdot 15.$$

According to the theory there is therefore no liability to buckling, and the calculated section might be adhered to, since formula (34) leads to a smaller value. According to the empirical equations given in XIII., on the other hand, the choice would have to be—

$$F = (1 + 0 \cdot 15)\, 59 \cdot 52 = 68 \cdot 45 \text{ square centimètres.}$$

This could be attained by keeping to the outer radius of 10 centimètres, by reducing the inner radius to 8·84, giving $F = 68 \cdot 6$.

Example 5.—The stress on a strut in the web of a bridge girder alternates between the tension $B_t = 40{,}000$ and the compression $B_d = 30{,}000$ kilogrammes. The sectional area for the length $l = 200$ centimètres, with reference to buckling, is to be determined, the ends being fixed.

From (30) or (23), and as already shown in Example 2, without liability to buckling, $F_d = 91 \cdot 43$ square centimètres. The strut is constructed in the manner of a plate girder, of four angle-irons, $8 \times 8 \times 1$ centimètres, and a web 32×1 centimètres; whence $F = 92$ and the smallest moment of inertia of the cross section, $I = 852$ centimètre-units. Formula (31) gives—

$$\mu = \frac{92 \times 200^2}{852 \times 24{,}000} = 0 \cdot 18,$$

so that here, too, by the theory there is no liability to buckling. If, however, the empirical formulæ are to be used, then from (40), since $(1 + \mu)\, B_d = 35{,}400 < B_t$.

$$F = \frac{40{,}000}{700\left(1 - \dfrac{35{,}400}{2 \times 40{,}000}\right)} = 102 \cdot 5 \text{ sq. centim.}$$

To make up this section the thickness of the angle-irons may be assumed as 1·2 centimètre, and then $F = 103 \cdot 0$ centimètres.

If the calculation were repeated with the more exact values of

F and I, there would result consecutively I = 1028, $\mu = 0{\cdot}17$, F = 101·82. Consequently a value of F has been determined too small by 0·68 square centimètre = $\frac{2}{3}$ per cent., an error that may be neglected.

Example 6.—To calculate the strut given in the preceding example for the length l = 300 centimètres.

In this case the provisional values of F and I are exactly as above; on the other hand $\mu = 0{\cdot}40$, and since $(1+\mu)B_d = 42{,}000 > B_{\mu}$ by (39)

$$F = \frac{42{,}000}{700\left(1 - \frac{40{,}000}{2 \times 42{,}000}\right)} = 114{\cdot}55 \text{ sq. centim.}$$

XVI. Conclusion.

It is possible, as already indicated, to find many deficiencies in the method demonstrated. But, there are here only two questions for consideration: (1) Does the method lead to the expectation of greater security than that hitherto used in determining dimensions? (2) Is not another newer method to be preferred? In order to facilitate in the latter particular the judgment and independent choice of his English professional fellow-workers the Author will be ready to give, in a second Paper, a short explanation and comparison of all the methods hitherto proposed. His object is mainly to supersede the present method of determining dimensions. Even if it is thought that other formulæ for a and b should be preferred, the general principles here demonstrated may yet have contributed to the elucidation of the question.

Since the strength of materials has recently acquired a fresh interest, it may well be that at no distant time satisfactory relations that will admit of general application may be discovered. The Author would welcome them with pleasure. It is sufficient for him to have contributed towards the supercession of the older method of determining dimensions, so as to make way for a more rational system.

(*Paper No. 1757.*)

"The Coefficient of Friction of Air Flowing in Long Pipes."

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THE value of the coefficient of friction of air flowing through long pipes is very imperfectly known. During the discussion of the Paper by Messrs. Culley and Sabine, the Author deduced from their experiments the value $\zeta = 0{\cdot}007$ for air flowing, approximately isothermally, in lead tubes $2\frac{3}{16}$ inches in diameter.[1] Since that Paper was published the Author has become acquainted with two series of experiments on the flow of air, carried out on a much larger scale, and furnishing a value of the coefficient of friction more reliable for general application.

In the "Cours d'Hydraulique" of M. Phillips, p. 300, there are given the results of some experiments on the flow of air by M. Arson. The coefficient of friction was found to vary sensibly with the velocity, and M. Arson adopted the well-known expression—

$$\zeta = \frac{\alpha}{v} + \beta$$

for the coefficient of friction, in which α and β are constants and v is the velocity of the air in feet per second. Reducing M. Arson's results to foot and pound units, the following values of α and β are obtained for cast-iron pipes:—

Diameter of Pipe. Foot.	α.	β.	ζ for 100 feet per sec.
1·64	0·00129	0·00483	0·00484
1·07	0·00972	0·00640	0·00650
0·83	0·01525	0·00704	0·00719
0·338	0·03604	0·00941	0·00977
0·266	0·03790	0·00959	0·00997
0·164	0·04518	0·01167	0·01212

It will be seen that at velocities exceeding 20 or 30 feet per second, the first term $\frac{\alpha}{v}$ in the expression for ζ is small. On the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliii., p. 270. The ζ in that Paper is four times the quantity usually termed the coefficient of friction. In this Paper it has been considered best to use ζ in its usual sense.

other hand ζ varies very greatly with the diameter of the pipe, as is known to be the case with water.[1] If an expression for the coefficient of air is used, similar to that adopted by Darcy for the friction of water,

$$\zeta = \alpha\left(1 + \frac{\beta}{d}\right),$$

where α and β are constants and d is the diameter of the pipe, then M. Arson's results, calculated for 100 feet per second, would agree fairly well with the value

$$\zeta = 0{\cdot}005\left(1 + \frac{3}{10\,d}\right),$$

differing from Darcy's value for the friction of water only in the last term, which in any case is not large, except for small pipes.

For the tubes of the Post-office pneumatic system, $2\frac{3}{16}$ inches, or 0·182 foot, in diameter, this gives—

$$\zeta = 0{\cdot}0048\left(1 + \frac{3}{10 \times 0{\cdot}182}\right) = 0{\cdot}0127.$$

The difference between this and the value 0·007 found for the pneumatic tubes is probably due to the different surface of the smooth lead pipes in the one case and the rough cast-iron pipes in the other. But under any circumstances M. Arson's experiments are valuable, as showing distinctly the influence of the diameter of the pipes on the coefficient of friction.

Recently M. E. Stockalper has published the results of some observations on the flow of air in the pipes laid in the St. Gothard tunnel.[2] M. Stockalper has used the results to show that Darcy's formula for the flow of water can be employed to calculate the flow of air, by merely multiplying the result by the ratio of the density of air to that of water. It is clear, however, that any formula of the form of Darcy's can only be approximate when applied to air, because it neglects the work due to the expansion of the air. It seemed therefore worth while to recalculate M. Stockalper's results by a formula strictly applicable to an expansible fluid.

The following Table gives the results obtained by M. Stockalper on the flow of air through pipes 0·656 and 0·492 foot in diameter. The larger pipes were partly of cast, partly of wrought, iron, with

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliii., p. 271.

[2] "Expériences faites au Tunnel de Saint Gothard, sur l'écoulement de l'air comprimé." Par E. Stockalper. Genève, 1879.

flange joints and india-rubber joint rings. The smaller pipes were of wrought iron, the joints being of the same kind. M. Stockalper's numbers have been reduced to pound and foot units.

The coefficient of friction has been deduced by the formula, given in the Minutes of Proceedings Inst. C.E., vol. xliii., p. 271,

$$\zeta = \frac{0{\cdot}611^2}{4\,W^2}\,\frac{d^5}{l\,T}\,(p_1{}^2 - p_0{}^2).$$

Experiment.	d Diameter of Pipe.	l Length of Pipe.	W Weight of Air Flowing per Second.	Mean velocity.	p_1 Pressure at beginning of Pipe.	p_2 Pressure at end of Pipe.	T Mean absolute Temperature.	ζ.
	Foot.	Feet.	lbs.	Feet.	lbs. per Sq. Ft.	lbs. per Sq. Ft.	Fahr.	
I.	0·656	15,092	2·669	19·32	11,852	11,090	531	0·00347
	0·492	1,712·6	2·669	37·14	11,090	10,582	540	0·00451
II.	0·656	15,092	1·776	16·30	9,207	8,741	531	0·00375
	0·492	1,712·6	1·776	..	?	?	..	..
III.	0·656	15,092	1·483	15·58	8,127	7,725	531	0·00410
	0·492	1,712·6	1·483	29·34	7,725	7,503	540	0·00447
			Mean for 0·656 foot pipe.					0·00377
			Mean for 0·492 foot pipe.					0·00449

These results again show that the coefficient of friction diminishes with an increase in the diameter of the pipe. They agree well with the formula

$$\zeta = 0{\cdot}0027\left(1 + \frac{3}{10\,d}\right),$$

which differs from that obtained in M. Arson's experiments in giving a smaller value of ζ. This expression would give $\zeta =$ 0·00393 for the 0·656 foot pipe, and $\zeta =$ 0·00435 for the 0·492 foot pipe. Also for the $2\frac{3}{16}$ inch tubes of the pneumatic system

$$\zeta = 0{\cdot}0071,$$

almost identically the same as the value derived from the experiments on those tubes. It should be mentioned that the temperature of the air rose from 17° to 28° Centigrade during the passage of the air through the whole length of pipes. This rise of 11° was due to conduction through the pipe walls. It would,

to some extent, have the effect of reducing the value of ζ, the loss of pressure being really less than the pressure lost in friction.

The results found by M. Stockalper would seem to merit confidence from the large scale of the experiments and the means available for securing a regular flow of air. That they show a much smaller frictional loss than had been inferred from previous experiments, he has already pointed out; and he has also remarked on the importance of this in the application of compressed air, in such works as those at St. Gothard.

The great influence of the diameter of the pipe on the coefficient of friction seems also to explain the difference between these results and those of Weisbach. Weisbach had given for the coefficient of friction of air values ranging from 0·012 to 0·028, or values from four to seven times as great as those obtained by M. Stockalper. Weisbach's experiments were made on small tubes about 2 mètres long, at velocities of 80 to 490 feet per second, and therefore the results do not merit great confidence. Still if the very small diameter of the tubes is allowed for, they diverge much less from M. Stockalper's results than they appear to do at first. The following Table contains a comparison:—

	Diameter of Tube. — Inch.	ζ by Experiment.	ζ by Formula above.
Brass and glass tubes .	0·400	0·014 to 0·027	0·027
„ „ „ .	0·564	0·012 „ 0·026	0·020
Zinc tube	0·960	0·013 „ 0·023	0·013

MEMOIRS OF DECEASED MEMBERS.

MR. JOHN HENRY ABBEY was born in the year 1831, and began his professional career as a pupil of Mr. Thomas Brook, surveyor, Huddersfield, after which he entered the office of Mr. Martin, a civil engineer of Leeds. In the year 1853 he was appointed surveyor to the Huddersfield Improvement Commissioners but resigned in 1857 to commence practice on his own account, and to take up appointments rendered vacant by the death of his uncle Mr. Mallinson Abbey, as surveyor to several important turnpike trusts and landed estates. On the incorporation of the borough of Huddersfield in 1868 he was elected borough surveyor, and in that capacity rendered valuable assistance to the corporation in the promotion of and carrying into effect several improvement bills; but owing to numerous engagements he resigned that appointment in August 1879.

He attained considerable eminence as a valuer, and his general knowledge and experience led to his being extensively employed in arbitration cases. He was architect of the new borough offices in Ramsden Street, and also of the public hall now in course of completion in Princess Street. Mr. Abbey was elected an Associate of the Institution on the 11th of May, 1869, and was transferred to the class of Members on the 27th of November, 1877. He died, after a short illness, of cancer in the stomach, in the fiftieth year of his age, on the 27th of November, 1880.

SIR THOMAS BOUCH, the third son of William Bouch, a retired captain in the mercantile marine, was born in the village of Thursby, Cumberland, on the 22nd of February, 1822. The village school of Thursby was for a time conducted by Mr. Joseph Hannah, and the elementary part of Thomas Bouch's education was acquired under that teacher, who still survives, and who has given interesting information regarding the early career of his subsequently distinguished pupil. For a time, the boy showed no greater inclination for study than is usual with an average village lad, and the beginnings of his interest in learning are attributed to a curious cause. Fond of out-door exercise, hunting, &c., he was

more prominent in the rougher traits of school life than in attention to his teacher, and in the annual carnival of "barring out"—when the scholars occupy the schoolhouse, and defy the master till some concession as to holidays, &c., has been gained—Thomas Bouch took an active part. It appeared to Mr. Hannah that this rather barbarous and demoralising practice might give way to a more rational procedure, and he persuaded his boys to come to the schoolhouse to a lecture on Natural Philosophy. Bouch was the last to give in, but, deserted by his comrades, he too attended. Many years afterwards he confessed to his teacher that the lecture (which treated of ways of raising water in ancient and modern times) had not proceeded far before he found his whole attention engrossed, and he began to wish the master would talk till night! He at once took to reading books on the subject of Mechanics, "Ferguson's Lectures on Select Subjects" being a favourite volume. This stimulus appears to have eventually led him into that career wherein he won distinction. Mr. Hannah removed from Thursby to take charge of an old-established school in Carlisle, and there Thomas Bouch followed him, completing his education about the year 1840.

His first entrance to business was in a mechanical engineering establishment in Liverpool, but he did not find this congenial or suitable for his tastes, and after a short interval he returned to Carlisle. At the age of seventeen, he was engaged by Mr. Larmer, civil engineer, who was then employed on the construction of the Lancaster and Carlisle railway, under Messrs. Locke and Errington. Here Mr. Bouch remained about four years, giving such satisfaction that Mr. Larmer asked Mr. Hannah, "if he could send another youth as well qualified to act as assistant." In November 1844, Mr. Bouch proceeded to Leeds, where he was occupied for a short time under Mr. George Leather, M. Inst. C.E. Subsequently he was for four years one of the Resident Engineers on the Stockton and Darlington railway, under the late Mr. John Dixon, Engineer-in-chief, and in that position took part in many important engineering operations for the Company.

In January 1849, Mr. Bouch left Darlington to assume the position of manager and engineer of the Edinburgh and Northern railway, subsequently known as the Edinburgh, Perth and Dundee, and now absorbed in the North British system. This engagement first brought to his notice the inconvenient breaks in railway communication caused by the wide estuaries of the Forth and the Tay, the efforts to remedy which afterwards occupied so much of his attention.

His first proposal was to cross the estuaries by convenient steam ferries; and he soon prepared and carried into effect plans for a "floating railway," a system for shipping goods trains which has now been in operation for thirty years.[1] From the discussion at the Institution in 1861, ten years after the system had come into operation, it would appear that several plans and suggestions, more or less nearly approaching that carried out by Mr. Bouch, had previously been in existence. But the dictum of the late Mr. Bidder, who was President at the time, may be accepted, that "there was little merit in a simple conception of this kind, as compared with a work practically carried out in all its details, and brought to perfection." With the exception of such slight accidents as are perhaps inevitable in working such a system, it has been used daily, in all weathers, and with unqualified success, during the whole period since it was erected under Mr. Bouch's direction. It may be mentioned that the "Leviathan," the vessel first employed on this service on the Forth, was built by the late Mr. Robert Napier, M. Inst. C.E., of Glasgow, and was brought round from the Clyde, by the north of Scotland, in weather which fully tested its sea-going qualities. Mr. W. Hall, M. Inst. C.E., from whose Paper some of the above particulars are taken, urged the success of the scheme as a plea for its more general adoption.

Shortly after completing this work, Mr. Bouch left the service of the Northern railway, and engaged in general engineering business. The railways actually carried out on designs by Mr. Bouch embraced the Darlington and Barnard Castle, 20 miles; the South Durham and Lancashire Union, 50 miles; the Eden Valley, 22 miles; the Cockermouth, Keswick and Penrith, 31 miles; the Sevenoaks and Maidstone, 20 miles; the Peebles (long the pattern for cheap construction), 21 miles; the Kinross-shire, 10½ miles; the Leven (Fife), 6 miles; the Leslie, 5 miles; the St. Andrews, 5 miles; the Crieff Junction, 9 miles; the Coatbridge undertaking, 8 miles; the Edinburgh, Loanhead and Roslin, 6 miles; the Leadburn, Linton and Dolphinton, 10 miles; the Penicuick, 6¼ miles; the North British Arbroath and Montrose (on the eve of completion at his death), 16 miles; the Newport (Fife), 6 miles; the Tay bridge, tunnel, station, and connecting lines, 8 miles; and the Edinburgh Suburban Railway, 8 miles, for which powers were obtained last session. In addition to the lines actually constructed, Mr. Bouch's name is associated with a number of plans of railways which from various causes were not

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xx., pp. 376–390.

carried out. In 1861, he was engineer of a scheme to connect Edinburgh with Perth by a new line, carrying the trains across the Forth at Queensferry by an adaptation of the "floating railway," which had then been proved by ten years' experience at the wider crossing at Burntisland. Some years later he projected the Glasgow and North British railway, with a bridge over the Forth above Queensferry, which will be noticed further on. In 1864 he was the author of an important scheme for completing the "inner" and "outer" circles of the London system, and his proposals were in part adopted by the Joint Committee of Lords and Commons which sat on this question, and from whose labours sprang the "District" railway. On the introduction of the tramway system, Mr. Bouch was extensively engaged in laying out lines, including some of the London tramways, the Edinburgh, Glasgow, and Dundee tramways, and others.

In the course of his professional work, Mr. Bouch constructed a number of remarkable bridges, chiefly in connection with railways. At Newcastle-on-Tyne, he designed the Redheugh viaduct, described by him as a compound, or stiffened-suspension bridge. It consists of four spans, two of 260 feet, and two of 240 feet each. Its piers, formed of four grouped pillars of 3 feet in diameter, with horizontal cast-iron girders and diagonal wrought-iron bars, are 80 feet above high water, being the same height as the high-level railway bridge. His principal railway bridges, independent of the Tay bridge, were the Deepdale and Beelah viaducts on the South Durham and Lancashire Union railway, the Bilston Burn bridge on the Edinburgh, Loanhead and Roslin line, and a bridge over the Esk at the Montrose end of the North British, Arbroath and Montrose line. The Beelah viaduct presents a design of sixteen spans of 60 feet, the greatest height being 196 feet. The piers consist of a group of six columns, two centres and two rakers on each side, with a diameter of 12 inches. The Deepdale viaduct has eleven spans of 60 feet, with a maximum height of 160 feet. At Bilston the bridge is constructed with stone piers, and has six spans of 70 feet, with a maximum height of 150 feet. In a bridge crossing the Tees, the spans, five in number, are 120 feet each, with a maximum height of 130 feet, the piers being, as in the Bilston bridge, constructed of stone. In all these bridges Mr. Bouch made use of the lattice girder, because of its simplicity and its slight resistance to the wind encountered at such high elevations.

After the "floating railway," already described, had come into operation, Mr. Bouch's attention was drawn to the desirability

of having a more direct connection between the north and south of Scotland, by carrying uninterrupted railway communication across the two estuaries of the Forth and the Tay. Taking the Forth first, besides laying out the scheme for a railway ferry at Queensferry, he projected the Glasgow and North British railway, plans for which were lodged in 1864, and in which it was proposed to cross the estuary by a fixed bridge. This was proposed to be 3 miles long, and was to extend from the south side to a point called the Stacks, about a mile above Charleston on the Fife shore, the piers consisting of wrought-iron cylinders supported on a wide base on the silt bottom of the river. An experimental pier for this bridge was prepared and partly sunk to its place, attracting much attention amongst professional men at the time. The bridge was to have been 125 feet above high-water level, and five of its spans were to have been 500 feet each, to cross the fairway of the river. After considerable progress had been made with the experimental pier, the project was abandoned, on the failure of Mr. Hodgson's policy as chairman of the North British railway. The question of bridging the Forth was, however, not lost sight of by Mr. Bouch, who in 1873, after the Tay bridge had been begun, projected a design of a much bolder character. He removed the point of crossing to Queensferry, where the width was much reduced, but the depth much increased. Taking advantage of the island of Inchgarvie, in the middle of the estuary, as a foundation for a central pier, he proposed to cross the deep-water channels on each side by two spans of 1,600 feet each, elevated 150 feet above high-water line. Each span was to be supported by suspension chains, having a deflection of 375 feet, the stiffening necessary for railway traffic being provided by tie-rods and stron lattice girders. The piers were formed of cast-iron columns, strongly braced, and their total height from the foundation was upwards of 600 feet. The advantages promised by this scheme were so great that the several railway companies, both English and Scotch, who were interested in the traffic on the eastern side of the kingdom, eagerly professed their willingness to support it, if it were practicable: but on account of the unexampled boldness of the design, they stipulated that it should be submitted to the opinion of some of the highest engineering authorities in the kingdom. Accordingly a committee of four eminent engineers, Sir John Hawkshaw, Messrs. W. H. Barlow, G. P. Bidder, and T. E. Harrison, were appointed for the purpose, and at their suggestion an elaborate investigation of the proposed design, in full theoretical

and practical detail, was undertaken by Mr. W. H. Barlow and Dr. Wm. Pole, assisted on some points by the Astronomer Royal, Sir G. B. Airy. Their report was given on the 30th June 1873, and it was so favourable that the four referees pronounced an unqualified approval of the plan. They said: "It affords us great satisfaction to be able to give our sanction to a work of so imposing a character, and to express our high approval of the skill, scientific research, and practical knowledge which have been brought to bear upon the elaboration of this interesting work." It is right to add that in the designs of this, as of many other important structures, Mr. Bouch was assisted by Mr. A. D. Stewart, of Edinburgh, whose high mathematical attainments and great practical experience in iron construction, were of much advantage to him.

Some years elapsed, in consequence of financial difficulties, before the scheme took a practical shape, but in 1878 a company was formed, the contracts for the Forth Bridge were let, and on the 30th September in that year the works were formally begun.

Although Mr. Bouch had, as early as 1849, expressed his determination to bridge both estuaries, it was not till 1863 that the first proposal for a Tay bridge was made public, and not till July 1870 that the Bill for this purpose received the royal assent. As originally designed, the Tay bridge differed in some of its details from the scheme ultimately carried out. As eventually built, the bridge was within a few yards of 2 miles long: it consisted of eighty-five spans, namely, seventy-two in the shallow water on the north and south sides varying from 29 to 145 feet; and thirteen larger spans over the fairway channel, two of these being 227 feet, and eleven 245 feet, wide. The rails rested on the upper members of the girders generally, but on the lower members of the thirteen large spans. The system of wrought-iron lattice girders was adopted throughout, Mr. Bouch adhering to the form of construction which had been successfully employed in other works designed by him. The piers were originally intended to be of brickwork, but after the fourteen nearest the south shore had been thus erected, the fifteenth showed a failure of the anticipated foundation, which led to the abandonment of brick and the introduction of iron. In the lesser piers the group of pillars consisted of four of 12 inches diameter, and for the larger spans six pillars were used, disposed in two triangular groups of three each, and stiffened with cross bracing. After many vicissitudes and delays caused by unexpected difficulties in carrying out the work, the line was completed continuously from shore

to shore on the 22nd of September, 1877, after which date there was a heavy ballast traffic across the river, testing the carrying power of the bridge in a satisfactory way. The inspection of the work by Major-General Hutchinson, R.E., on behalf of the Board of Trade occupied three days, and on the 31st of May, 1878, the bridge was opened with much ceremony and rejoicing, the engineer being presented with the freedom of the town of Dundee. Traffic on the bridge was at once begun, and a direct service of trains from Edinburgh and Glasgow to Aberdeen was organised, saving much time and inconvenience by the abandonment of the ferry crossing and the double change of conveyance it involved. The improvement was fully appreciated by the public, and in June 1879 the Queen crossed the bridge on her journey southwards from Balmoral. As a mark of royal approval of the striking achievement of the engineer, the Queen commanded the attendance of Mr. Bouch at Windsor, and on the 26th of June, 1879, he received the honour of knighthood.

The traffic was continued uninterruptedly till the evening of Sunday the 28th of December, 1879, when a violent hurricane arose, and during the passage of a train from Edinburgh across the bridge, the central portion fell into the river, carrying with it the entire train and its load of about seventy passengers, all of whom lost their lives. An inquiry was instituted by the Board of Trade into the circumstances of the accident, the evidence showing much conflict of opinion as to its cause. There could be no doubt, however, of the almost unprecedented violence of the gale, and Sir Thomas Bouch strongly held the opinion that under this force some part of the train had left the rails, which he considered would amply account for the disaster. He had for some time not been well, and under the shock and distress of mind caused by the casualty his health more rapidly gave way, and he died at Moffat on the 30th of October, 1880. In his death the profession has to lament one who, though perhaps carrying his works nearer to the margin of safety than many others would have done, displayed boldness, originality and resource in a high degree, and bore a distinguished part in the later development of the railway system.

One unfortunate effect of the disaster was to paralyse the operations that had been favourably going on towards the larger project of crossing the estuary of the Forth. The public had, for the moment, lost faith in large iron bridges; the Board of Trade made larger demands of security, and the Forth Bridge Company, rather than persevere in so bold a scheme in the face of

a temporarily unfavourable phase of public opinion, resolved to abandon the undertaking, or at least to wait till a more convenient season for its further prosecution. There must, however, be a feeling of universal regret at the loss to the public, without any sufficient cause, of the enormous advantages offered by a scheme so favourably launched, and which would have been so great a credit to the engineering talent and commercial enterprise of Great Britain.

Sir Thomas Bouch married in July 1853 Miss Margaret Ada Nelson, who survives him with one son and two daughters. He became an Associate of the Institution on the 3rd of December, 1850, and was advanced to the class of Member on the 11th of May, 1858. His brother, the late Mr. William Bouch, was long connected with the locomotive department of the Stockton and Darlington and North Eastern lines.

Mr. WILLIAM CLARK was born at Colchester, on the 17th of March, 1821. His education was obtained principally at King's College, London, which he entered in 1842, and where he was so distinguished for industry and diligence, that, on the termination of his three years' course, he was made an Associate of the College. Soon afterwards he became a pupil of, and subsequently an assistant to, Mr. Birkinshaw, M. Inst. C.E., under whom, first as assistant and afterwards as resident engineer, he was employed for a period of three or four years on the works of the York and North Midland railway system. In 1850 he was connected with the late Sir Goldsworthy Gurney, who at that time had charge of the warming and ventilating of the Houses of Parliament. In 1851 he entered into partnership with Mr. A. W. Makinson, M. Inst. C.E., the firm devoting special attention to the warming and ventilating of public buildings. He was shortly afterwards offered and accepted the appointment of surveyor to the Local Board of Health of Kingston-upon-Hull, and devised a complete system of drainage for that town, the works of which were commenced by him. In 1854 he entered the service of the East Indian Railway Company as a second-class engineer. After acting for upwards of a year as resident engineer on a portion of the East Indian railway, forming part of the district under Mr. Sibley, M. Inst. C.E., he became the secretary, and subsequently the engineer, to the Municipality of Calcutta, who were considering what could be done to im-

prove the sanitary condition of that city, then in a very unsatisfactory condition. Mr. Clark devoted himself with characteristic zeal and ability to this work, and after a comparatively short interval, spent in making the necessary surveys and inquiries into the local circumstances, was enabled to propose a complete scheme for the drainage of Calcutta.[1] In preparing this he found the great advantage of his previous acquaintance with drainage work, especially as required for low-lying towns, built on the alluvial soil, on the shores of navigable rivers. His scheme for the drainage of Calcutta was much in advance of the views of the Municipal Council, who were not only incredulous as to the improvement in public health which might be expected from such a thorough drainage as Mr. Clark proposed, but were also startled by the suggestion to lay out a sum of money much larger than had previously been contemplated for such improvements. The scheme was, therefore, warmly opposed: in Calcutta he had to live down prejudice and misrepresentation. He felt that he was capable of doing the city justice if only its citizens would believe in him, and see for themselves what well-directed energy could achieve. But the President of the Municipality regarded him with jealousy; several of the native Justices of the Peace opposed a stolid resistance; and even newspapers ceased not for years to speak of him with scurrility. Ultimately, owing to the steadfastness and ability with which Mr. Clark supported his views, the Council were won over to allow a portion of the plan, devised as an experiment, to be carried into effect. Under Mr. Clark, as engineer, the drainage was successfully carried out, without the aid or assistance of any contractor, native labour being employed departmentally. This was the first instance in which the improved drainage system of England had been initiated and adopted in the populous cities of India. The success of this work, and its marked influence on the state of the public health in Calcutta, were most complete.

In addition to the drainage, Mr. Clark devised a complete system of waterworks for Calcutta, comprising three large pumping stations with their filter beds and settling tanks, all of which were executed under his charge and personal supervision. Mr. Clark continued to act as engineer-in-chief to the Municipality of Calcutta until the commencement of 1874, when he

[1] *Vide* "Letter from the Municipal Commissioners to the Government of Bengal, forwarding a report on the drainage of Calcutta, by W. Clark, dated the 29th December, 1855."

returned to England and entered into partnership with Mr. W. F. Batho, M. Inst. C.E. In the same year Mr. Clark received the appointment of consulting engineer to the Oudh and Rohilkund Railway Company. In December, 1874, Mr. Clark visited Madras, where he remained for four months planning a system of drainage for that city: he submitted to Government an able report thereon,[1] but the work was not carried out for want of funds.

In 1876, at the recommendation of Mr. G. R. Stephenson, Past-President, Inst. C.E., Mr. Clark was selected by the Colonial Office and appointed by the Government of New South Wales, to advise and report upon the water supply and drainage of Sydney. During a residence of two years in the Australasian colonies, he prepared several schemes of a like description, embracing the towns of Port Adelaide, Newcastle, Bathurst, Goulbourn, Orange, Maitland, Brisbane,[2] and subsequently Wellington[3] and Christchurch in New Zealand. Mr. Clark's plan for the drainage of Christchurch was commenced in 1879, the sewage pumping machinery having been designed and erected under his supervision, and dispatched with a considerable quantity of pipes.

Among Mr. Clark's inventions may be mentioned his "tied brick arch," of which fine constructive examples exist in Calcutta and other places in India; he was also joint patentee with Mr. W. F. Batho of the now well-known steam road-roller. Among his schemes may be mentioned the proposal for reclaiming the salt-water lakes in the neighbourhood of Calcutta.

Having suffered for about six months from a liver affection, the germs of which were doubtless laid in the country to which he had devoted the best of his life, Mr. Clark died at Surbiton, on the 22nd of January, 1880. Mr. Clark was elected a Member of the Institution on the 2nd of February, 1864: he was also a Member of the Institution of Mechanical Engineers.

By sterling integrity and honourable conduct as an engineer, by a generous and kindly disposition in private life, together with his manly influence and example, Mr. Clark will long be favourably remembered.

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[1] *Vide* "Report on the Drainage of Madras." Folio. Madras, 1875.

[2] *Vide* State Papers. New South Wales and South Australia, 1877, 1878.

[3] *Vide* "Report on the Drainage of the City of Wellington, and disposal of the Sewage." Folio. Wellington, 1878.

In Mr. FREDERICK JOHN EVANS the Institution has lost a member who stood deservedly high in that branch of the profession to which he devoted exclusive attention, namely, that of gas manufacture and gas lighting. He was born in 1818. His father, Mr. John Evans, was one of the district engineers of the first gas company ever established, namely, the Gas Light and Coke Company (commonly called the Chartered Company), and resided at their chief station in Horseferry Road, Westminster. Hence the son, who was naturally intelligent and clever, became in his earliest youth thoroughly acquainted with the processes going on around him; and so well did he take advantage of his opportunities that at the age of sixteen he obtained an appointment in the service of the company. He left it for a short time to occupy a post in the gas works at Berlin, but returned in 1839, after which time he remained with the Chartered Company till his death. In 1844 he was appointed superintendent of one of their stations in Finsbury; and, in 1848, he removed to Westminster, occupying the position formerly held by his father. In 1863 the late Mr. George Lowe, M. Inst. C.E., who had been the chief consulting engineer of the Company almost from its formation, retired, and Mr. Evans, having by this time gained a high reputation by the ability he had shown in the management of the works entrusted to him, became his successor. The affairs of the Company were then in a critical position. They had three manufacturing stations, namely, in Westminster, Finsbury, and Shoreditch. Each was in a populous district, surrounded by houses, and although the demand for gas was constantly increasing, there was no possibility of extending them. Moreover, the Company was only paying 6½ per cent. dividend (although they had Parliamentary power to pay 10 per cent.), and no means were available of either increasing their income or diminishing their expenses, and they were exposed to the mortification of seeing the increased demand supplied by rival companies springing up around them. In this juncture Mr. Evans undertook a very bold measure. An idea had been thrown out, some years before, by the late Mr. Bidder, Past-President Inst. C.E., with his characteristic largeness of conception, that the gas for supplying London ought to be manufactured in the suburbs, and sent into the town for consumption. Such an idea was treated by the gas companies generally as, if not chimerical, at least commercially impracticable; and nobody had ever thought seriously of carrying it into execution. But Mr. Evans had a large faith in the future of gas lighting, and after carefully

weighing all the circumstances of the Company, in conjunction with the energetic secretary, Mr. J. O. Phillips, Assoc. Inst. C.E., he recommended the directors to apply for power to take a tract of land in the eastern suburbs of London, and to establish there a gas manufactory of great capacity, from which the gas should be conveyed into London by large conduit mains. This, he argued, would have three great advantages: it would admit of extension to any amount in order to meet the constantly-growing supply; it would largely conduce to economy by giving a better access for the coal, and by allowing improvements in the manufacture generally; and thirdly, it would lead to the abolition of the nuisance of gas-making in the heart of London. The proposal was, after mature consideration, adopted by the directors; it was laid before Parliament in 1866, and again in 1867, but it only received parliamentary sanction in 1868; the result being the establishment of the Beckton Works on the banks of the Thames, nearly opposite Woolwich. This is the most magnificent establishment of the kind in the world; it was opened in 1871, and will long remain a monument of the enterprise of the Company, and the professional skill and judgment of their engineer. Such a bold and successful measure gave the Company a prestige which led to other important changes. During the discussions which had taken place in Parliament attention had been drawn to the disadvantages that arose from the gas supply of London being in the hands of so many individual commercial interests, some at rivalry with each other. Hence the policy of amalgamation was recommended, and in the Act of 1868 Parliament gave powers to the Company to absorb, if they could arrange to do so, certain of the Companies supplying the City. The establishment of the Beckton Works put the Company in the most favourable position possible for enlarging their business, and in 1870 they took over the entire affairs of three other Companies, namely, the "City of London," the "Great Central," and the "Victoria Docks" Gas Companies. These amalgamations were soon followed by others; in 1871 the Chartered Company absorbed the "Equitable"; in 1872 the "Western"; in 1876 the "Independent"; and in the same year they made their largest amalgamation by joining with the Company only second in magnitude to themselves, namely, the "Imperial." An idea of the effect of these combinations may be formed from the fact that before the amalgamations in 1870 the annual make of the Company was about 1,300,000,000 cubic feet per annum; whereas at present it has increased nearly twelve-fold, namely, to 12,350,000,000 cubic feet, a quantity

which represents about two-thirds of the whole metropolitan supply. There can be no doubt that this policy of amalgamation has been most beneficial in all respects; it has given the public gas of better and more uniform quality, with more efficient distribution, and at lower price than could otherwise have been obtained; and it has ensured to the shareholders not only largely improved dividends, but a firm and powerful commercial position. Mr. Evans was always a warm supporter of amalgamation, and was ever ready, by skilful engineering arrangements, to turn every new accession to the best advantage. In 1872, seeing his great work substantially accomplished, he retired from his active official position, and was, as a well-merited compliment, placed on the Board of Directors.

He had no ambition to intrude into branches of the profession which were strange to him; but, in compensation, he had made himself thoroughly master of every kind of knowledge bearing on gas manufacture. He was fond of original investigation, one result of this being his discovery, nearly thirty years ago, of the valuable properties of oxide of iron for gas purification, which revolutionised the conduct of that process. In 1868 a Board of three Referees was appointed by Act of Parliament to settle, from time to time, certain questions in regard to the quality of the metropolitan gas supply; and Mr. Evans, notwithstanding his connection with the chief gas company, was nominated by the Government as one of these—a flattering testimony to his high principle and independence of character. He enjoyed personally the esteem of all who had either business or private relations with him.

Mr. Evans was elected an Associate of the Institution on the 10th of March, 1840, and was transferred to the class of Members on the 9th of February, 1864. He was struck down suddenly, while engaged in scientific experiments in a room exposed, in hot weather, to a powerful sun, and he died a day or two afterwards, on the 8th of July, 1880.

Mr. HENRY DAVID FURNESS, the second son of the Rev. John Robson Furness, Vicar of Dinnington, Northumberland, was born in 1830, and was educated at the collegiate school, Leicester. In July 1847 he was apprenticed for four years to Messrs. Robert Stephenson and Co., of Newcastle-upon-Tyne, but for one year of this time worked in the erecting shop of Messrs. Robert Napier

and Sons, Glasgow. From September 1853 he was for two years Chief Engineer on board steamers belonging to the Steam Navigation Company of the Two Sicilies. He next obtained an appointment in the Turkish navy as engineer during the Crimean war, after which he became sub-manager of the works at Messrs. Robert Stephenson and Co.'s factory under the late Mr. William Weallens, M. Inst. C.E. He subsequently went to Russia as locomotive superintendent on the Riga-Dünaburg railway, and continued there after the amalgamation of that line with the Dünaburg and Witepsk, until the year 1869. He then accepted the post of locomotive superintendent on the Orel-Witepsk railway; but the work and the climate told so severely on his health that he was obliged to return to England in 1870.

After a rest of a few months he recovered sufficiently to occupy himself in the invention of a lubricator for locomotive cylinders, which is now extensively used both at home and abroad. He also carried on business at Newcastle as a consulting engineer. He had been to Suez on professional business, and was on his way home when he died at Marseilles, of liver complaint and heart disease, after an illness of only ten days, on the 2nd of November, 1880. Mr. Furness was elected a Member of the Institution on the 5th of March, 1867. He was possessed of an eminently mechanical turn of mind, had clear judgment and great uprightness of character, and his amiable temper earned for him the confidence of all with whom he was brought into contact, professionally and privately.

MR. THOMAS HIGINBOTHAM was born in Dublin, in the year 1820. He was the third son of Mr. Henry Higinbotham, a merchant of that city. He received a sound general education at Castle Dawson school, near Blackrock, and he afterwards attended the drawing and mathematical classes and lectures at the Royal Dublin Society House, Kildare Street, Dublin, where he acquired the rudiments of his professional education. About the year 1840 he left Ireland, and entered the office, in London, of Sir William Cubitt, Past-President Inst. C.E., then in the front rank as a Civil Engineer. Shortly afterwards, the railway mania reached its height; Sir William Cubitt's office was full to overflowing of work of all kinds, and Mr. Higinbotham had opportunities, of which he diligently availed himself, of gaining complete and accurate knowledge of the theory and of the indoor practice of railway construction, and of the proceedings

before railway committees of the House of Commons. He was subsequently appointed assistant engineer on the Ashford and Canterbury branch of the South-Eastern railway; and he again filled a similar position on another branch line in Lancashire. Having won the approval and confidence of his superiors in these works of construction, he was next promoted to the office of resident engineer on the Huntingdon section of the Great Northern railway, of which Sir William Cubitt was the consulting engineer. After the completion of this line Mr. Higinbotham practised in London for two or three years, and at the end of the year 1857 he emigrated to Victoria. Shortly after arriving in Melbourne he was invited by the Government to accept the office of Chief Engineer of Roads and Bridges of the colony. Three years afterwards he was appointed Engineer-in-Chief of Victorian railways, and he continued to hold that office until the month of January 1878, when, as a result of the conflict which then took place between the two Houses of the Legislature, and the political excitement which followed thereon, he, together with county court judges, police magistrates, and other officers of high rank in the public service, were all removed from their offices. His services were sought for during the two succeeding years by the Governments of the adjoining Australasian colonies of South Australia, Tasmania, and New Zealand. In March 1880 he consented, at the request of the Premier, the Hon. James Service, to resume the position of Engineer-in-Chief of Victorian railways; and he continued to hold that office until his death, which happened suddenly on the 5th of September in the same year. In 1874 Mr. Higinbotham was commissioned by the Government of Victoria to visit Europe and America, for the purpose of studying the railway systems of the principal countries of the world, and of acquainting himself with the latest improvements, whether in construction or in management, that might be found in any of them. He devoted himself zealously to the fulfilment of this mission, and the results of his inquiries, which extended over a period of a year and a half, were embodied in an exhaustive report, which was laid before Parliament.

The railways of Victoria were, at the beginning of the year 1880, 1,182 miles in length. The bulk of these lines were designed and constructed under the superintendence of Mr. Higinbotham, and they are thoroughly sound and substantial in their general character. With the exception of the trunk lines from Melbourne to Sandhurst, from Footscray to Williamstown and to Geelong, and from Geelong to Ballarat, which were designed and partly

constructed before Mr. Higinbotham became Engineer-in-Chief, the average cost per mile of the Victorian railways has been £7,212. The uniform gauge of all the railway lines in Victoria is 5 feet 3 inches. Uniformity of gauge has not been adhered to in the adjacent colonies of New South Wales, South Australia, and Tasmania; and in Queensland, where the gauge is uniform, it is only 3 feet 6 inches. The Government of Victoria, some years ago, proposed that a narrower gauge than 5 feet 3 inches should be adopted for the new and cheaper lines which were then about to be constructed. To this proposal, which was powerfully supported by the newspaper press, Mr. Higinbotham felt it to be his duty to offer the most uncompromising opposition; his official remonstrances, and his evidence given at the bar of the Legislative Council, had the immediate effect of delaying the carrying out of the proposal; and ultimately, after the lapse of a parliamentary recess, Mr. Higinbotham had the satisfaction of finding the Government and the whole community converted to his views on a question which he regarded as of vital importance.

As the permanent head for nearly twenty years of a large department, and chiefly responsible for the prudent and economical expenditure of many millions of money borrowed on public credit for the construction of railways, Mr. Higinbotham earned and generally obtained, in a more than usual degree, the trust and confidence of the Government of Victoria. He was sensitive in regard to his rights and public obligations as a member of the profession of civil engineers, and he never shrank from what he believed to be the duty of clearly expressing and recording his professional opinion, however inconvenient or unpalatable, upon any matter coming within the scope of his official functions as the professional adviser of the Government. But in the administration of a public department he never forgot the duty of submission to the advisers of the Crown under whom he served; and it was his constant endeavour in practice to observe the duty which he conceived that he owed to his profession, and to himself as a member of a profession, as well as that which his official superiors were entitled to claim from him. As an administrator he was strict and vigilant, and at the same time just, and amongst the very many to whom his personal qualities endeared him, there were few who regretted his death more sincerely and deeply than those who served the Crown under him and with him in the public service of Victoria. Mr. Higinbotham was elected a Member of the Institution of Civil Engineers on the 7th of February, 1854.

MR. MAXIMILIAN HJORTSBERG was born in Stockholm, Sweden, on the 8th of November, 1825. He was the youngest son of Lars Hjortsberg, a learned and highly cultivated man, and was accustomed from early childhood to the society of intelligent and distinguished foreigners, as well as natives of his own country, and was educated at the University of Upsala. After some preliminary training as an engineer in the Polytechnic School at Stockholm, and in other parts of his native country, he, at the age of nineteen, removed to London, where he was engaged as assistant with the late Mr. Cheffins, Assoc. Inst. C.E., and the late Mr. C. H. Wild, Assoc. Inst. C.E., with whom he remained about two years. He subsequently joined the staff of Mr. John Fowler, Past President Inst. C.E., by whom he was employed in the construction of the docks at New Holland, and the railways connected therewith, till 1850. In that year he visited North America, and travelled extensively in the United States and Canada. In 1851 he returned to his native country, but left it in the following year for the United States, where he settled permanently. For a time he was engaged as one of a firm of contractors on a railroad in Southern Indiana, and had charge of a portion of the Ohio and Mississippi railroad, under Colonel Henry Flad, now Commissioner of Public Works in St. Louis, Mo. In 1857 he made Chicago his residence, and in the next year took a subordinate position on the Chicago, Burlington, and Quincy railroad, from which in a short time he rose to be the chief engineer. This position he filled until 1879, during which time he planned and constructed for that railway an important bridge across the Mississippi river at Burlington, and several branch roads. In the discharge of these duties he exhibited a thorough knowledge of details, and combined, in the works committed to his care, adaptability, durability, and economy, in such a manner as to leave no room for unfavourable criticism. A service like this, by far the longest and most important of his life, brought out traits of character and evidences of ability which caused Mr. Hjortsberg to be highly appreciated, and gave him an enviable position among the intelligent portion of the community.

During the last two years of his life Mr. Hjortsberg was much interested in the subject of furnishing steam to cities for heating buildings, and for motive power, from central boiler stations, through pipes laid in the streets, and became thoroughly convinced, not only of its practicability, but of its economy in many

respects. His last position was that of engineer of the Pullman Palace Car Company at Kensington, about 16 miles south of Chicago. It was while in discharge of his duties there that he met with the very painful accident which caused his death about three weeks after, on the 16th of May, 1880.

In matters of taste, as well as engineering skill, Mr. Hjortsberg stood deservedly high; and his reputation in this respect caused him to be appointed twice the superintendent of construction of one of the most beautiful churches in the city; once before and once after the great fire. He was appointed by the governor of the state in 1878, and continued until his death, one of the Lincoln Park Commissioners, an office without emolument, but requiring for the faithful performance of its duties great responsibility in the expenditure of money, much care and judgment in the adoption of plans for the protection of the river, along the shore of Lake Michigan, from the effect of storms; and a combination of good taste and economy, exceedingly difficult to find, in the laying out and ornamenting of the grounds.

Mr. Hjortsberg was elected a Member of the Institution of Civil Engineers on the 5th of May, 1868. He [manifested his interest in the advancement of engineering in his adopted country by becoming a member of the American Society of Civil Engineers, and served for several years as one of the executive committee of the late Civil Engineers Club of the North-West, now the Western Society of Engineers. He was also a member of the Chicago Historical Society, and of the Chicago Literary Club, organizations that have for their object the faithful preservation of the records of the past, and of the upholding of a high literary standard in the future.

In all relations with his employers, his professional brethren and society, he maintained not only the reputation accorded him already for ability in the discharge of his engineering duties, but for thorough uprightness that has never been called in question. He was somewhat reserved in manner, for which reason those who did not penetrate the outward crust did not always understand, and could not correctly appreciate, him; but to those who shared his intimate friendship, his unusual intelligence, his fine taste in matters of literature and art, and his personal excellence, were not only manifest, but very attractive.

MR. EDWARD JOHNSTON, the eldest son of the late Admiral E. Johnston, was born in Ireland on the 17th of September 1816. He was educated in France, and after leaving college, in 1832, was for some time employed on the Great Trigonometrical Survey of England. In 1834 he was articled to the late Mr. O. D. Owen, and on the expiration of his pupilage was employed on the Chester and Holyhead railway, and on the parliamentary surveys and plans of the Great Northern railway, the western extension of the Caledonian railway, and the Central Devon and Cornwall railway. From 1850 to 1856 Mr. Johnston was in practice on his own account, during which time he designed and completed the main drainage of the city of Bangor, the Bangor Waterworks, and the Port Penrhyn branch railway, besides furnishing plans for Port Penrhyn dry docks. On the 4th of March 1857 he received an appointment as a third-class assistant engineer on the Madras railway, and attained the rank of first-class on the 13th of June, 1862, remaining in the service of the company till the 6th of January 1872. During this period he was for some time engaged in the construction of the Goriatum and Palar bridges on the south-west line, and from February 1860 to February 1862 was in charge of the Chey-Air bridge on the north-west line, of which work he contributed an account to the Institution,[1] and for that Paper he was awarded a Telford Premium. He had at various times charge of districts 4, 5, 8, and 13, and several times acted as deputy chief on construction. For the last year of his service he was on special duty. In March 1873 Mr. Johnston joined the Public Works Department of the Government of India, as an executive engineer, 4th grade. He was employed for some time on the Indus Valley railway, and afterwards in the north-west provinces and in Oudh. He was among the many engineers whose services were dispensed with in the great reduction in the Public Works Department in October 1879. He returned to England in January 1880, and died at Southsea, from paralysis, on the 26th of the following July. Mr. Johnston was elected a Member of the Institution on the 4th of March 1862. His hospitality was unlimited, and was extended alike to friends and strangers. Many will recall with gratitude the kindness and forethought which marked their reception when, after a hot day's march over the plains that stretch from Cuddapah to Bellary, they came to Edward Johnston's bungalow. He was an excellent sur-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiv., p. 184.

veyor, a good organiser of labour, a very neat draughtsman, and gained the esteem of his employers in the different situations which he filled.

MR. JOHN SHELDON WILKINSON was born at Spalding on the 22nd of May, 1837. He was a younger son of the late Mr. W. C. Wilkinson, surgeon of that town. After being for some time at the grammar school of his native place, he proceeded to the St. Albans grammar school then under the mastership of the Rev. Henry Hall; and even at this time he gave proof of those tastes which determined the choice of his profession, for whilst a schoolboy he showed no little ingenuity in constructing working models of machinery. In the autumn of 1854 he entered King's College, London, as a student in the Applied Science Department, and passed through its two years' course with much credit, especially evincing his skill in the workshop; and the practical acquaintance with tools here acquired stood him in good stead in the after exercise of his calling. About Christmas 1856 he was articled to Mr. W. M. Brydone, M. Inst. C.E., then chief engineer to the Great Northern Railway Company. At the expiration of his pupilage he continued in the employment of the Great Northern railway, being engaged for twenty months in the rebuilding of the bridge over the Witham at Bardney, between Boston and Lincoln, on their loop line. In the execution of this work he was considered to have shown good skill, as the reconstruction had to be effected in a morass, and by its stability it has proved the judgment shown in its erection.

From this work Mr. Wilkinson became contractors' engineer, having charge of the construction of part of the Aylesbury and Buckingham railway. Then for two years he was chief assistant-engineer on the Great Northern railway. When the Great Northern and the Manchester, Sheffield and Lincolnshire railways determined on carrying out their Cheshire line as a joint undertaking, he was the resident engineer engaged in their superintendence. But about this time Mr. Wilkinson determined to commence business on his own account, and took up his residence in Manchester, where he continued for the most part to reside until his premature death, though he was then making arrangements to remove his main office to London, where for some time he had had a branch.

His first work in independent practice was the construction of

the West Cheshire railways, in connection with which undertaking he carried out their main line from Northwich to Helsby, together with several branches intended for the accommodation of the salt traffic in and about Winsford. In the prosecution of this work the viaduct at Northwich, which is about ½ mile long, was an important feature. In the spring of 1870 he was appointed engineer for the Chester and West Cheshire Junction railway, which was opened for traffic in May 1875. In this was included a large terminal station at Chester, in connection with which there was some rather difficult contriving, as the station is erected in part over the London and North Western Railway Company's line from Chester to Holyhead. In the autumn of 1871 the works in connection with the Manchester, Stockport and Romiley railway were placed in Mr. Wilkinson's charge, and were of a somewhat heavy character in consequence of the treacherous nature of the ground.

His last work of magnitude was the Manchester South District railway, originally planned as an independent undertaking, but eventually taken up and carried out by the Midland Railway Company, who have transferred their Manchester traffic to this line, which they now use as their main line from London, giving them admission to the new Manchester central station.

Since the introduction of the tramway system into England, Mr. Wilkinson had been engaged as engineer in carrying out several schemes, notably the Swansea tramways; and he was at the time of his death consulting engineer to the Hull tramways. Mr. Wilkinson was struck down by paralysis in his 43rd year, and died on the 23rd of June, 1880, sharing the fate of so many professional men of the present day who, in the hurry and worry of business, fail to find the needed intervals of leisure to enable them to recuperate their energies. Thus too often in early middle life are lost to the service of the world the accumulated stores of practical knowledge and experience, which might prevent many a blunder and carry out many an important work. Thus, it is true, openings are made again for younger men to prove what is in them; but as those in middle-life see, one after another, the friends of their youth dropping out of the race, they cannot but feel saddened, and they must needs think that the same amount of work spread over a longer period of life would leave room for a more full development of the many sides of man's life and character.

Mr. Wilkinson was elected a Member of the Institution of Civil Engineers on the 3rd of December, 1867.

MR. EDWARD MIDDLETON BARRY, R.A.,[1] the third son of Sir Charles and Sarah (*née* Rowsell) Barry, was born in London on the 7th of June, 1830. He was educated at the well-known private school of Dr. Greig at Walthamstow, and afterwards at King's College School, London, when at the age of sixteen he began his studies for the profession of an architect. His health during his early years was not robust; and this fact, rendering him to a great extent unable to join in boyish sports, probably induced in him a self-contemplative cast of thought which was always one of his characteristics. His amusements during this period were thus of a sedentary character, and he was remarkable in the family circle for the ingenuity with which during boyhood he would carry out the scenery and mechanism first of a toy theatre, mechanical conjuring tricks and devices, subsequently the scene painting and arrangements for private theatricals and other similar entertainments, of which, in his father's house, he was always the promoter and head. In these and other ways he showed at an early age signs of that ability for the mechanical details of construction, and for planning and picturesque treatment of buildings, which at a more mature age were remarkable in his career as an architect. He showed also, even at this period of his life, great ability with his pencil, and high artistic powers, though from the circumstances which have been stated he was unable to pursue with any great vigour sketching from nature or from actual buildings. In these and similar ways he evinced such a decided predilection and innate power, both of mind and of hand, fitting him for the profession which he afterwards pursued and adorned, that, although his elder brother, Charles (late President of the Royal Institute of British Architects), had already joined the profession, it was decided that the younger brother should also follow his father's footsteps. On leaving King's College he entered as a pupil the office of the late Mr. Thomas Henry Wyatt, Assoc. Inst. C.E., and after a short term of pupilage under that architect, he joined his father, Sir Charles Barry, as an assistant, his elder brother Charles having by that time commenced practice on his own account. Sir Charles was then at the height of his professional career, and his son Edward had not only unusual opportunities of seeing the execution of some of the most important buildings of the present century, but also had the advantage of

[1] Biographical notices of Mr. Barry have appeared in "The Transactions of the Royal Institute of British Architects," 1879–80, p. 201; in *The Builder*, vol. xxxviii., p. 147; and in other periodicals.

studying under the ripe artistic powers and experienced practical knowledge of his father. He became a student of the Royal Academy in 1848, regularly attended the lectures there, and also studied his profession assiduously at home after the ordinary labours of the day, and during the hours usually devoted by youths of his age to recreation. The advantages he possessed from early experience under his father, coupled with his own great natural endowments and industry, soon showed their result in the competitions which then were, as they now are, so strangely customary for architectural works. Competitions were then to him the means of great distinction, but were in his later life the source of much unmerited disappointment. During his early years he thus gained several premiums, amongst which were the designs for the Oxford University Museum (though the execution of the work was entrusted to another competitor), the Birmingham and Midland Institute, and other less important buildings. He also executed the following works before he had attained the age of thirty years: St. Saviour's Church, Haverstock Hill; the Birmingham and Midland Institute; the Leeds Grammar School; the Royal Italian Opera, Covent Garden; the Floral Hall, Covent Garden; Henham Hall (alterations); Duxbury Hall; St. Giles's Schools, Endell Street, and some minor works, all of which were undertaken when he still held the arduous post of chief assistant to his father, and when therefore he was constantly engaged in the building of the Houses of Parliament, which were almost completed in the year of the death of Sir Charles Barry. At the death of his father in 1860 Mr. E. M. Barry was appointed by the Government to the post of Architect to the Houses of Parliament; and carried out some important work connected with that building, including the completion of the Victoria Tower, the cloisters and subway and enclosure of New Palace Yard and Parliament Square, the restoration of the crypt of St. Stephen's Chapel, &c. This position he continued to occupy at the Houses of Parliament under many changes of Government with the confidence of all, until his resignation in 1870. No successor was appointed to the post, but the building was placed under the immediate control of the officials of the Office of Works.

Subsequent Governments, and the Houses both of Lords and Commons, continued to call on Mr. Barry from time to time for consultative advice, and one of his last employments was advising a committee as to some proposed minor alterations of the Houses of Lords and Commons. He had also prepared, at the request of the Government, in 1868, elaborate and careful plans for the enlargement of the existing House of Commons, and, as an alter-

native, for the construction of a new House, using the present House as a members lobby. In 1867 he was invited by the Government, with eleven other architects, to compete for the New Law Courts, and at the same time he was one of ten architects invited to compete for a new National Gallery. In the competition for the National Gallery he was placed first. In that for the Law Courts the first place was given to him, bracketed with Mr. Street, by the judges of the designs, viz., Mr. Gladstone, Mr. W. Cowper, Sir. A. Cockburn, Sir R. Palmer, Mr. W. Stirling, Mr. Shaw, and Mr. Pownall, who were called in by the Government to select the most meritorious design. By the architectural judges, Messrs. Shaw and Pownall, who were, in the case of the Law Courts, entrusted with the adjudication on the relative merits of the plans, apart from other considerations, he was placed *facile princeps*. The Government, however, objected to the joint appointment of Mr. Barry and Mr. Street, and referred the award back to the judges. Mr. Barry and Mr. Street were formally asked whether they were willing to act conjointly, and on their answering in the affirmative the judges stated to the Government that they would not alter their award. On the refusal to reconsider this award, the law officers of the Crown were consulted, and advised that the joint award was invalid, and that owing to this circumstance the conditions of the competition were not binding on the Government. The Government then appointed Mr. Street to erect the Law Courts, and Mr. Barry to build the new National Gallery. But the new National Gallery has never been erected, and thus Mr. Barry was placed in the extraordinary position of having gained the first place in both these important competitions, and of being denied the opportunity which either of them would have afforded him, and which he earnestly desired, of leaving his name to posterity connected with such a work. It is not too much to say that the results of these competitions probably hastened Mr. Barry's untimely death. These matters unquestionably preyed on him, and, telling upon a constitution never over strong, resulted in a deficiency of elasticity of mind and body, which showed itself in gradually increasing proportions for a year or two previous to his death.

As an architect Mr. Barry occupied an independent position between the Gothic and Classic schools of thought, refusing to be bound by the trammels of either. He was able to see the beauties and the weaknesses of both styles, and as a matter of fact practised himself largely in both. The St. Giles's Schools in Endell Street, his work at the Houses of Parliament, the Leeds

Grammar School, and Crewe Hall, are examples of his work in Gothic and Elizabethan architecture. The Opera House at Malta, his designs for the new National Gallery, the Art Union of London, are instances of his Classic architecture; and the mansions of Shabden, Cobham, and Wykehurst, and the Temple Buildings show his powers in the Renaissance style. His mind, which was eminently practical as well as artistic, revolted from any pedantry of style which would render a building of the present day unfitted for modern use. His great aim was always to make the most of modern science and modern improvements in order to meet the requirements of the time, without sacrificing the artistic beauties of the older styles; and he refused to be bound by the means and knowledge of building which belonged to bygone ages merely for the reason that they were old. Thus his mind was eminently catholic in art, and for this reason, as well as from his knowledge of construction, he was fitted to assist, and was always willing to co-operate with, engineers, with a view to a due consideration of the artistic demands of any of their various structures.

Mr. Barry was elected an Associate of the Royal Academy in 1861, an Academician in 1869, and Treasurer of that body in 1874, which post he held at the time of his death. He had also occupied the chair of Professor of Architecture at the Royal Academy for three sessions, and was engaged this year in the delivery of his final course of lectures, three of which (subsequently printed) were undelivered at the time of his death. The work connected with the professorship and with the post of Treasurer was of an engrossing nature, and Mr. Barry felt keenly the responsibilities of the posi tion. As Treasurer he attended a meeting of the Academy on the extremely foggy night of the 27th of January, 1880, not feeling that he ought, even on the plea of health, to be absent from a meeting at which a subject he considered of importance was to be discussed, and he expired almost in the act of speaking at the Council table. The cause of his death was emphysema of the lungs, connected with a weak action of the heart.

To the members of the Institution of Civil Engineers, of which he was elected an Associate on the 7th of February, 1860, he was well known, not only from his frequent attendance at the meetings, but also from his having served as an Associate Member of Council, and he was endeared to many by feelings of friendship or affection. On the night of his death he had dined with several members of the Council, the association with whom he often said gave him the greatest pleasure. He had a keen appreciation of the profession of a Civil Engineer, and was often loud in his admiration of the

magnificent works which during his career, embracing as it did the years so important in engineering history, from 1845 to 1880, he had seen executed by the engineers of this and other countries. As an architect he lamented the shortcomings of many engineering works in artistic taste, and often pointed out that there was no necessary incompatibility between the engineering necessities of such works and artistic conception; but, on the contrary, that these structures afforded, from their magnificence of scale, their importance and cost, grand opportunities for what is called architectural treatment. He often said in his lectures and elsewhere, that if the possibility of detailed embellishment and the charm of beautiful materials were often denied to the engineer, he generally had at his disposal that power of effecting a beautiful result which is due to care of the principles of proportion of parts, to magnitude, and to the general design of a structure considered as a whole. With his knowledge of construction and use of materials, combined as it was in him with great artistic power, he often wished for that union of the architectural and engineering professions, securing both the æsthetic and scientific aspect of construction, which was seen in the early architects of the middle ages, and of the Italian renaissance. This union, he thought, ought never to have been broken, and he was at times sanguine enough to hope that it might perhaps be some day restored.

The social qualities and gifts of Mr. Barry were remarkable and well known; his information and reading in the literature of his profession, as well as upon general subjects, and his power of expressing his views and criticisms in society were such as to make his table-talk and general conversation most interesting. Mr. Barry was a Vice-President of the Royal Institute of British Architects, Honorary Member of the Imperial and Royal Academy of Vienna, and Member of the Royal Academy at Amsterdam.

MR. WILLIAM FREEMAN was born on the 25th of April, 1793, at 27, Millbank Street, Westminster, where, upon the death of his parents, Joseph and Sarah Freeman, he carried on the business of stone and granite merchant in partnership with his brother John. In 1865 his brother retired from the firm, and carried on the Cornish granite quarries, and William Freeman took his son, John Russell, into partnership, upon whose death, in January 1878, he resigned the business to a nephew and grandson, and retired to live

at Twickenham Green, where he died on the 6th of May, 1880, full of years and respected by numerous friends.

He was well known in Westminster for his connection with the various charities, and was, until a few years before his death, treasurer of Mr. Emery Hill's almshouses and also of the City of Westminster Savings Bank. For upwards of twenty years before his death he was totally blind.

Mr. Freeman was elected an Associate of the Institution of Civil Engineers on the 23rd of February, 1836.

Captain HENRY SIDNEY FREEMAN HAYNES, R.E., the eldest son of the late Mr. Freeman Oliver Haynes of Lincoln's Inn and Wimbledon, barrister-at-law, was born on the 4th of October, 1845. He was educated at Wimbledon School, and from there passed into the Woolwich Academy, obtaining the highest number of marks for mixed mathematics. He received his first commission in the corps of Royal Engineers on the 20th of August, 1865, and spent the usual two years' course of study at Chatham. From February 1868 to October 1869 he served on the fortifications at Portland and Weymouth. He was then transferred to India, where, from January 1871 to the end of his career, he was exclusively employed on railway work; first as an assistant engineer on the Indus Valley State Railway, then as deputy consulting engineer to the Government of India in the railway department. Subsequently he was posted to the account branch railway department, and officiated, first at Lahore and afterwards at Calcutta, as deputy examiner of accounts. At the time of his death he was officiating as deputy consulting engineer to the Government of India for guaranteed railways.

He was elected an Associate of the Institution of Civil Engineers on the 1st of December, 1874, and attained the rank of Captain in the corps of Royal Engineers on the 22nd of May, 1878. He had been suffering from rheumatic gout, and was on leave at Naini Tal, when the landship occurred on the 18th of September, 1880, and he was entombed in the *débris* of the second slip, but the body was subsequently recovered.

MR. RALPH WARD JACKSON, the third son of the late Mr. William Ward Jackson, of Normanby Hall, in the North Riding of Yorkshire, was born on the 7th of June, 1806, and was educated at Rugby. Having served his articles at Preston as a solicitor, he entered into partnership with Mr. Frank, of Stockton, and carried on with him a considerable practice. In 1838 he took a share in the establishment of the Stockton and Durham County Bank, the business of which was in 1846 transferred to the National Provincial Bank of England. About the year 1836 Mr. Jackson became connected with the management of the Clarence railway, in the county of Durham. The Act for this line was obtained in 1828, and it was opened in 1832; it was made for the purpose of transporting coals from the pits to a shipping place on the north side of the river Tees, at Stockton, with another terminus, also on the north side of the Tees, some miles nearer to its mouth, at a shipping-place which was named Port Clarence. Stockton-upon-Tees had already been adopted, in about 1825, by the Stockton and Darlington Railway Company for a like purpose. In 1830 this line was extended to Middlesbrough. In 1835 a railway had been constructed to Hartlepool. This had led to the creation of a small harbour, in which the coals were shipped, and whence the ships proceeded at once to sea. In 1840 a dock, in connection with this harbour, was opened. When Mr. Jackson became associated with the Clarence railway, he at once saw that an improved shipping-place was desirable. It had been found that the shipment of coals in the tideway of a rapid river was exposed to great inconveniences, and that it was essential to obtain the security of dock accommodation. The Stockton and Darlington Company, having gained similar experience, constructed, in 1842, a dock at Middlesbrough; but the entrance was out of the tideway of the Tees, involving still the risks to shipping of its tortuous navigation, dangerous sandbanks, and the bar which existed at its mouth. Instead of suggesting a dock at Port Clarence, with an entrance from the Tees, Mr. Jackson proposed that, from a place called Billingham, a branch line of railway, of about 8 miles, should be made into the bay of Hartlepool, which should have its outlet at the sea itself. This line was to be called "The Stockton and Hartlepool Union Railway." The company was formed in 1838, and was composed of most of the shareholders in the Clarence railway, with others. The late Mr. Henry Vansittart, of Kirkleatham Hall, a large proprietor in the Clarence railway, was the first chairman of the directors. On his retirement he was succeeded by Mr. Jackson.

Having reference to the outlet to the sea for the coals brought over the Clarence and Stockton and Hartlepool system into the bay of Hartlepool, it was seen that it would be desirable to take advantage of the then existing harbour and intended dock there, if arrangements could be made, where rival interests were concerned. The proprietors, however, were principally, if not entirely, colliery owners. Their new works had been constructed to supply a shipping-place for the coals belonging to the Hartlepool and Coxhoe district. The public port, as such, had existed for two or three hundred years. There were commissioners, whose duties had been confined to the interests of a few fishermen, and the pier, and trifling works required for their protection. The shipment of coal, of course, materially increased the resources of the old trust. Great opposition was threatened to the formation of the connecting line between the Clarence and Hartlepool. Mr. Jackson then conceived the idea of forming the line by "way leaves," *i.e.*, by obtaining the consent of all owners of land without an Act of Parliament. The Stockton and Hartlepool railway, after great perseverance, was opened in 1841, Mr. John Fowler, Past-President Inst. C.E., being the resident engineer. The completion of this line, without any Parliamentary powers, was, in fact, the basis upon which West Hartlepool now stands. The formation of the company, and the whole of the works, were subsequently confirmed by Act of Parliament. The powers were, in some respects, different in those early days to what, in later years, were ordinarily adopted. When Mr. Jackson first connected the towns of Stockton and Hartlepool, the latter had not long ceased, as before stated, to be a fishing-town and watering-place. In regard to the new railway, it was proposed to form a shipping-place within the old Hartlepool harbour. Pending the solution of this question, arrangements were made with the old company to receive and ship the coals brought by the Stockton and Hartlepool railway. This agreement was made for a specific period of three years, upon terms not considered very liberal. Had it not been for the policy of the old company, which discouraged the shipment of coals from any other districts in their harbour, the port, which derived its revenues from the dues upon everything that was shipped within its limits, would have been proportionately benefited. As a consequence, however, of this opposition, which received its final practical solution in the ruinously heavy charge imposed by the old company in shipping any coal but their own, Mr. Jackson was driven to start a harbour and dock on the west side of the bay of Hartlepool, and so control the ship-

ments of the Clarence system. This spot was named West Hartlepool. In 1844 Mr. Jackson took a bill into Parliament for the formation of the new harbour and its first dock. The opposition was serious. But, eventually, Parliamentary powers, in some respects of an exceptional nature, were obtained for "The Hartlepool West Harbour and Dock." The late Mr. James Simpson, Past President Inst. C.E., was the engineer who designed the works. The area was only 13 acres in the harbour and 8 acres in the dock. On the 1st of June, 1847, they were opened. In 1852 the Clarence, Stockton and Hartlepool and the Harbour and Dock Companies were amalgamated by Act of Parliament, under the title of "The West Hartlepool Harbour and Railway Company;" and Mr. Jackson was elected the chairman of the first board of directors. He became an Associate of the Institution of Civil Engineers on the 4th of March, 1851.

The difficulties of forming piers in the best direction in those early days were great. The ever-changing nature of the large sand collections had to be contended with. These were especially due to the variable currents, winds, and storms, on the east coast of England, and in the Tees bay in particular. Though the new harbour was within the port of Hartlepool, it was carried into a much more exposed part of the bay, on account of the works of the old company; two simple north and south piers of Mr. Simpson had to be remodelled; and it was inevitable that success could only be attained by experience and experiment of a costly description. In all these matters Mr. Jackson, under the advice of the late Mr. Thomas Casebourne, M. Inst. C.E., was ceaseless in his industry and indomitable in his energy. In the end, the harbour was enabled to be kept clear of sand with scarcely any dredging; and by a series of inner piers, designed by Mr. Jackson, which formed a unique system of "wave traps" in the outer harbour, the sea was so broken that the lock gates, though only about 400 yards in a direct line from the pier head, were enabled to be worked with ease and safety at all times. The ultimate expense was greatly reduced by all the piers being, in the first instance, made of timber. These were, with little cost, altered as experience proved necessary; and, finally, were filled in and encased with permanent masonry.

In 1848 a proposition was made to connect Leeds with Hartlepool, which was completed in 1853. Mr. Jackson immediately urged upon the directors the desirability of larger dock accommodation. He also further extended the feeders to West Hartlepool, by promoting the North Yorkshire and Cleveland railway, and

so connecting it with the great iron fields then only recently discovered. On the 1st of June, 1852, a second dock was opened, called the Jackson dock; and on the 3rd of June, 1856, a third dock was opened, called the Swainson dock.

In 1851 West Hartlepool had become so far developed, and displayed such signs of vigour, that a magnificent piece of plate was presented to Mr. Jackson by "The Merchants, Shipowners, Tradesmen, and others, in recognition of his services in creating the Port." In 1855, the town still growing apace, his portrait, painted by the late Sir Francis Grant, P.R.A., was presented to the commissioners in trust for the town; and in 1862 the leading merchants and others of the city of Hamburg presented Mr. Jackson with a valuable testimonial, in proof of their appreciation of the advantages which had accrued to them by the opening of another port for steamers on the north-east coast of England. The population of West Hartlepool had risen from 400 in 1840 to about 4,000 in 1847, and to about 15,000 in 1862. The area of harbour and dock accommodation, at West Hartlepool alone, was increased from 21 acres to about 90 acres in the same time. The shipments of coal rose from 150,000 tons in 1848 to about 1,000,000 in 1862. The value of exports from about £250,000 in 1854 to £5,500,000 in 1862; and of imports in the same proportion. On the occasion of the redistribution of seats by the Reform Bill of 1868, "The Hartlepools" were created a Parliamentary borough; and Mr. Jackson was elected the first member, and continued to sit for it, in the Conservative interest, during the six following years. He was also Chairman of the West Hartlepool Commissioners for fifteen years; President of the Athenæum; and a Commissioner of the Port and Harbour board. An enormous amount of money had been necessarily expended on the sea and land works at West Hartlepool in a very short space of time. Large sums had been invested in steamers, for the purpose of carrying on the trade with Rotterdam, Hamburg, Antwerp, &c., owing to the development of the traffic with Leeds and Lancashire. It had been necessary, in order to enable the newly established locality to grow with the rapidity which its communications required, to acquire large surrounding properties, for new stations, docks, and timber ponds; the latter being especially large for the great trade which had sprung up with the Baltic. All these requirements were fulfilled in the course of less than fifteen years from the original foundation of the undertaking. It was not, therefore, a matter of much surprise that the expend ture was somewhat in advance of the returns. Questions arose as to the powers which existed under such early Acts of Parliament, and it became desirable that these

powers should be more clearly defined. Whilst these were in course of reorganisation Mr. Jackson retired from the chair of the company in 1862. Negotiations had been opened with the North-Eastern Railway Company, and in 1865 an amalgamation took place, and the West Hartlepool Harbour and Railway Company became part of the North-Eastern system. The united harbours and docks of "The Hartlepools" now consist of about 220 acres. Mr. Jackson had, since his retirement, taken no part in the management of the place he had founded. He lived in London, after leaving his residence, Greatham Hall, near West Hartlepool. His health had for some time been failing, and he died of paralysis, after three weeks' illness, on the 6th of August, 1880, in his seventy-fifth year. On the day of his funeral the strongest evidences and expressions of respect for his memory were everywhere displayed.

He had interested himself, for the last year or two of his life, in measures for the improvement of Whitby harbour; and contributed materially to obtaining an act of Parliament for enlarging the jurisdiction of the port. During the years 1879 and 1880 a proposal had met with great encouragement to raise a sum of money, for the purpose of perpetuating, at West Hartlepool, the memory of its founder. Subscriptions to a considerable extent had been received when the stroke of death removed him from this world. This, however, has not impeded, if even it has not stimulated, the kindly and just appreciation of the labours of his life, which had such a material influence in the early development of railway enterprise.

Mr. CHARLES LÖWINGER was born in 1823 at Budapest, where his father was a wholesale stationer. He carried off the first prizes in Latin and mathematics at the Gymnasium of that city, and commenced the career of an operatic artist in Germany; but the revolution of 1848 frustrated his hopes in that direction, and he became book-keeper in a commercial office at Hamburg. Early in 1850 he came to London, and in the following year, on the opening of the Great Exhibition, obtained employment as an interpreter in the Lord Mayor's Court. While occupied in this capacity he attracted the attention of Mr. Crampton, M. Inst. C.E., who engaged him as his foreign correspondent. His brilliant social qualities, especially his musical attainments, made him a great favourite, and opened for him the portals of society, where his amateur operatic acting was much applauded, and brought him invitations to noblemen's country-seats. This

was the happiest period of his life. His small but well-appointed house in Berkeley Square became the rendezvous of great artistes, and his musical matinées were much frequented by the fashionable world. His health then failed, and for twelve months he was unfitted for business. Upon recovering he returned to the scene of his former labours an apparently healthy, high-spirited man. His ambition was to promote a great undertaking for the benefit of his native country, the Francis Canal, in which he invested almost all his fortune. That undertaking, however, did not pay, and all his other enterprises failed. He died of heart disease in Westminster on the 27th of November, 1880. Mr. Löwinger was elected an Associate of the Institution of Civil Engineers on the 14th of April, 1863.

Mr. WILLIAM OWEN[1] was a native of Rotherham, where his father, Mr. Luke Owen, carried on business as a maltster. He was apprenticed to the pattern-making business with Messrs. Sandford and Yates, at the Phœnix Foundry, in Greasborough Road, and retained his connection with that establishment until the day of his death. In 1825, two years after he had joined the business, he was one of thirty men and boys exclusively engaged in the making of cast-iron goods. Other branches of the iron trade were acquired by the firm, and for some years he acted as their traveller. In 1832 he was admitted a partner in the business, and took the management of the forge and wrought-iron goods department. Ultimately Mr. Owen became the sole proprietor of the Phœnix Works, and carried on the business alone till March 1864, when the works were transferred to a limited liability company, of which he was appointed chairman and managing director, a position which he filled for eight or nine years.

Mr. Owen was the author of several valuable inventions for making solid wrought-iron wheels and tires. He took great interest in the welfare of the Royal Agricultural Society, and for many years officiated as one of their judges for machinery. He was one of the promoters of the Midland Wagon Company, and was for some years its chairman. Mr. Owen was elected an Associate of the Institution of Civil Engineers on the 3rd of March, 1857. He died at Rotherham, after a lingering illness, on the 20th of January, 1881, aged seventy years, regretted alike by his friends and workmen.

[1] This notice has been compiled from the *Rotherham and Masbro' Advertiser* of January 22, 1881.

MR. THOMAS HENRY WYATT[1], the eldest son of the late Mr. Matthew Wyatt, Barrister-at-Law and Metropolitan Police Magistrate, was born at Loughlin House, Roscommon, Ireland, on the 9th May, 1807. It was originally intended that he should follow a mercantile profession, and he was sent to Malta for that purpose; but a short time before the death of his father he returned to England, and, being always fond of architecture, he entered the office of the late Mr. Philip Hardwick, R.A., M. Inst. C.E., and was afterwards placed by him in a position of considerable trust, in superintending the construction of the new warehouses then being erected at the St. Katherine's docks, upon the engineering designs of Mr. Telford. On leaving Mr. Hardwick, he commenced business on his own account, and obtained from the Metropolitan Magistrates the appointment of District Surveyor for Hackney, which he held for about thirty years, but eventually resigned, on account of the pressure of more purely architectural business.

Early in his professional career his talent and merits were recognised by the Duke of Beaufort, the Earl of Denbigh, the Pembroke family, especially by the then Mr. Sidney Herbert, and others, whose influence was of much service to him, and who entrusted him with carrying out many important works at Badminton House and other places. His professional work increasing rapidly, he took into partnership, in 1838, Mr. David Brandon, a connection which lasted thirteen years, and together they designed many important buildings, among which may be named the Cambridge County Courts, the Wilts and Bucks Lunatic Asylums, the Brecon and Usk County Courts, and many large mansions and private residences. After the termination of this partnership he continued the active exercise of his profession, and designed and carried out a large number of important buildings, among which must be specially mentioned the Exchange Buildings, Liverpool. He competed for the Town Hall, Manchester, and was one of the selected architects.

He was considered an authority on the arrangement of hospitals and lunatic asylums, and upwards of forty years ago was appointed honorary architect to the Middlesex Hospital. He designed two large hospitals for Malta, and also the Stockwell fever hospital, and at the time of his death was carrying out a new hospital for consumption at Brompton.

[1] Biographical notices of Mr. Wyatt have appeared in the Transactions of the Royal Institute of British Architects, 1879-80, p. 230; and in the *Builder* for August 14, 1880, vol. xxxix., p. 193.

The limits of this memoir preclude any detailed list of the very numerous architectural works upon which Mr. Wyatt was engaged, but a few may be selected as specimens of his peculiar skill and knowledge of his profession, especially as a compendious list of his works has been published in "The Builder" for August 14, 1880. He erected and altered a considerable number of mansions for the nobility and others. He built a large number of churches, among which must be mentioned Wilton church, in the Lombardic style, for Mr. Sidney Herbert—a church which may be said to have been the first during late years in which the revival of the use of Mosaic decoration was pre-eminent. He also, in conjunction with his brother, the late Sir Matthew Digby Wyatt, Assoc. Inst. C.E., built the garrison chapel at Woolwich, which showed how well iron and brick might be made to suit a truly ecclesiastical structure. The barracks and riding school at Knightsbridge were among his last great works, and although there were many difficulties in the way, still a large and imposing block of buildings of a characteristic and classical character has been realized. He was the honorary architect to the Athenæum Club, where he constructed, under considerable difficulties, some important extensions, on a site obtained, as a great favour, from the Government, chiefly by his own interest. He was consulting architect to the Church Building Society, special architect to the Board of the Wilts and Dorset Diocesan Society, and it may be said that he rarely declined to give advice and assistance to any public body asking his co-operation.

His distinctive power lay in rapidly conceiving and designing a plan suitable to the requirements of the particular case in hand. His power of sketching in a bold and telling way was remarkable, and his intimate knowledge of the peculiarities of various styles gave him great facility for meeting the wishes of his clients. As a man of business he was eminently modest, straightforward, and clearheaded; and to this he added a charming and agreeable manner, which contributed to his professional clients becoming his personal friends, at whose houses he was always a welcome guest, and who have expressed in a gratifying manner their sense of his loss. It was his invariable habit to acknowledge the assistance rendered to him by his pupils and assistants.

He was President of the Royal Institute of British Architects for three years, and also the President of the Architects Benevolent Society, in the formation of which he took a conspicuous position, and laboured hard in its favour in conjunction with his friend, Mr. George Mair, F.R.I.B.A. He was the recipient of the gold

medal given by Her Majesty for distinguished professional acquirements and great works.

Some years before his death he had taken into partnership his son Matthew, who rendered him valuable assistance, and who is now the last representative of a long line of architects and sculptors whose names and numerous works are so well known; as was natural, it was the wish of Mr. T. H. Wyatt that his son Matthew should be his successor, and devote himself to the completion of the works in hand at the time of his father's decease.

Mr. Wyatt was elected an Associate of the Institution of Civil Engineers on the 11th of March, 1845, was one of the auditors of accounts for the year 1847, and in the following year served as an Associate of Council. He was the honorary architect of, and was always consulted professionally by the Council on matters relating to, the building of the Institution; and it was on his plans and under his superintendence that it was reconstructed in 1847, and again in 1868, under the immediate personal direction of his son, Mr. Matthew Wyatt. The health of Mr. T. H. Wyatt had been visibly failing for some time, but such was his vital and moral energy that until within a short time of his decease he continued to go about among his friends, and even to see his clients. He died in Great Russell Street, London, on the 5th of August, 1880, and was buried at the village of Weston, near Basingstoke, the church which had been restored and rebuilt from his own designs, and partly at his own expense. Few professional men had so many attached friends as he had, and it will be many years before the good, kind genial friend and professional adviser will be forgotten.

Sect. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

On the Work of a Man for short Periods. By Dr. Hartig.

(Der Civilingenieur, 1880, col. 379.)

At the fire brigade congress at Dresden in June 1880, dynamometrical observations were made of the power required to work the different hand fire-engines exhibited. Amongst other results these experiments give an insight into the amount of work which can be performed by men working for very short periods at a lever.

The engines were placed in the open air, under a hot sun; they were worked by infantrymen, and each squad worked for two minutes only at a time. The following are selected from the Table of seventeen experiments given in the Paper:—

Number of experiment . . .	i.	viii.	ix.	xi.	xvii.	mean of 17.
Mean height of lever above ground . . . inches	40·25	38·7	38·54	49·31	38·38	..
Length of lever . . . . „	49·2	46·7	43·5	70·5	58·7	..
Stroke . . . . . „	38·8	35·0	35·9	45·5	37·4	..
Number of double strokes per minute	48	55	49	55	60	..
Mean velocity of handle . . . feet per sec.	5·17	5·33	4·9	6·95	6·23	5·78
Horse power exerted per man .	0·324	0·227	0·403	0·306	0·395	0·297

Morin and Weisbach give 5·5 mètre-kilogrammes per second = 2,387 foot-lbs. per minute as the work that a man can do for eight hours together; the above mean work is greater than this in the ratio $\frac{0{\cdot}297 \times 33000}{2387} = 4{\cdot}1$ nearly.

W. P.

Note on the Crushing Load of Building Stones. By M. de Perrodil.

(Annales des Ponts et Chaussées, August 1880, p. 83.)

Calcareous stones, the specific weights of which are given in the first column of the annexed Table, are crushed under loads given

in kilogrammes per square centimètre (0·00635 ton per square inch), which are shown in the second column.

Specific Weights.	Crushing Loads.
Kilogrammes.	Kilogrammes.
1·500	50
1·700	100
1·900	150
2·100	200
2·250	300
2·350	400
2·450	600
2·600	1,000
2·650	1,400
2·700	1,800

At Paris stones are divided into eight categories, according to the time which it takes a mason (paid 6 francs 50 cents per day) to dress a square mètre (10·76 square feet) of stone.

The categories of the stones and their crushing weights are given in the following Table :—

Limits of the Crushing Loads per square centimètre of Stones of the same category.	Average Time which it takes to dress a square mètre of the Stone.	Designation of the Category.
Kilogrammes.	Hours.	
50 to 100	2·8	8
100 „ 150	3·8	7
150 „ 200	5·6	6
200 „ 300	8·3	5
300 „ 400	11·3	4
400 „ 600	14·0	3
600 „ 1,000	19·6	2
1,000 „ 1,800	22·5	1

The resistance of sandstones to crushing is greater than the resistance of limestones for the same specific weights. The following Table gives particulars for sandstones between the specific weights of 1·870 and 2·570 kilogrammes :—

Specific Weights.	Crushing Loads per square centimètre.
Kilogrammes.	Kilogrammes.
1·870	150
1·950	200
2·050	300
2·100	400
2·200	600
2·300	700
2·570	900

For igneous rocks, comprising granites, there are not yet sufficient experimental results to enable a law to be established connecting the specific and the crushing weights. In the case of granites, it may be considered as proved that their crushing weights are greater in proportion as their grain is finer. Also granites change their structure gradually on account of the decomposition of the feldspar by water, and their strength diminishes rapidly as this decomposition progresses. The following Table gives the limits of the crushing loads for four qualities of granite :—

Description of the Granite.	Limits of the Crushing Load per square centimètre.
	Kilogrammes.
Undecomposed and fine grained	from 1,000 to 1,500
„ „ coarse grained	„ 700 „ 1,000
More or less decomposed and fine grained. . . .	„ 600 „ 900
„ „ „ „ coarse grained . . .	„ 400 „ 600

G. C. V. H.

Experiments on the Strength of Yellow Pine. By Prof. THURSTON.

(Journal of the Franklin Institute, vol. cx., p. 157.)

This Paper is an abstract of the results of experiments upon yellow pine of the ordinary market qualities, as determined in the laboratory of Stevens Institute. Special attention was given to the question of elasticity, and the moduli of the several specimens were carefully deduced.

At loads between one-third and one-half of the breaking weight the modulus of elasticity ranged from 1,689,000 in the instance of a piece of yellow pine, cut in Georgia in April 1879, to 2,869,000 in that of a kiln-dried strip from the middle of a stick cut in Florida in October 1879, the average value being 2,098,000. The modulus varied little with loads less than one-third of the ultimate; thus, a strip of old and thoroughly seasoned wood had a modulus of 2,249,000 with a load of 150, 2,288,000 with 450, 2,350,000 with 850, 2,394,000 with 1,450, and an average of 2,309,888 between the limits of 50 and 1,450, the breaking weight being 4,750.[1] With loads imposed for a considerable time, the deflection gradually increased, and the ultimate resistance was much less than in prices loaded steadily up to the moment of fracture. Professor

[1] This uniformity in the value of the modulus shows the suitability of strips of pine for the experimental solution of complex problems relating to continuous girders. See *Engineering*, vol. xxiv., p. 71.—B. B.

Thurston states that the maximum permanent load was probably something less than two-thirds, and more than one-half of that which would have been sustained under ordinary test.

None of the above specimens exceeded 54 inches span or 3 inches square, but four beams, of large section, were also tested, to see if results obtained with small specimens were applicable to such beams. The average of these experiments gave the reduced modulus of 1,387,156.

The general conclusions drawn by Professor Thurston, from the whole series of experiments, are that the elasticity of yellow pine timber,[1] as used in construction, is very variable, ranging from one to three millions, the average being about two millions in small sections, and a little above one and a half million in large timbers. The highest values are as often given by green as by dry timber, and the density does not determine the modulus. The modulus of rupture by transverse stress $R = \frac{3}{2}\frac{lw}{bd^2} = 10{,}000$ to 17,000, the highest values being generally obtained with well-seasoned wood.[2]

B. B.

The Manufacture of Portland Cement in Switzerland.

By Dr. H. FRÜHLING.

(Bulletin de la Société vaudoise des Ingénieurs et des Architectes, 1880, p. 9.)

After describing briefly the raw materials necessary to produce a good Portland cement, the Author proceeds to discuss the conditions prevailing in Switzerland. The Jura formation, so largely developed in that country, affords an inexhaustible supply of raw materials of good quality. One manufactory has been at work for several years at Luterbach, near Solothurn; another, the subject of this Paper, commenced work last year at Saint-Sulpice, Val-de-Travers. The raw material, which already possesses approximately the composition of raw Portland cement, is taken from the middle Jura formation, where it forms a layer of 23 feet. It is simply dried, pulverised, and made into bricks, which are afterwards burnt, producing Portland cement clinker. The composition of the raw material is continually checked by means of analyses executed in the laboratory of the works. A plan and sections of the works are given, together with drawings of the kilns erected. The material is worked by means of galleries, into which a small tramway runs. The rails of this tramway are level with the top of

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[1] Pitch pine.—B. B.

[2] In Mr. Edwin Clark's treatise on "The Britannia and Conway Tubular Bridges," vol. i., p. 461, an experiment upon a rod of yellow pine, by the late Mr. I. K. Brunel, is described.—SEC. INST. C.E.

the drying kilns, into which the stone is tipped. On leaving these kilns the dry stone falls into trucks, in which it is carried up an inclined plane to the crushers. These, which are on Motte's system, reduce the stone to a coarse powder, which is then carried by an elevator to a store-room. Thence it passes into the horizontal mills, where it is converted into an impalpable dust. In this form it is again raised by an elevator into trucks, which convey it into large wooden tanks. Here the powder is saturated with water, the plastic mass thus produced being afterwards moulded into bricks by a machine. These bricks are dried upon plates heated by the waste heat from the coke ovens. In twenty-four to thirty-six hours they are sufficiently dry to place in the burning kilns, in which they are mixed with the necessary amount of coke. The kilns used are of the usual intermittent type, the local conditions not being favourable for the erection of a Hoffman kiln, although this would have rendered the operation of burning continuous. The clinker, after having been freed from all imperfectly burnt fragments, is passed through a second group of crushers and mills, emerging from the latter in a state fit for consumption. The whole of the motive power is supplied by turbines, and is estimated at 250 HP.

Tables are given showing the strength of the cement manufactured at Saint-Sulpice, as compared with that of a number of German manufacturers. The tests, which were made at the official testing station at Berlin, indicate a strength of 84·27 kilogrammes per square centimètre (1198·5 lbs. per square inch) in thirty days, when tested neat, and 26·48 kilogrammes per square centimètre (376·6 lbs. per square inch), in the same period of time when mixed with 3 parts by weight of standard sand. The experiments were made with the apparatus originally constructed by the Author, and since adopted by the Prussian Government as the standard testing machine. During the winter 1879–1880 samples of this cement were exposed to temperatures varying from − 10° Centigrade (14° Fahrenheit), to − 20° Centigrade (− 4° Fahrenheit), without showing signs of deterioration.

W. F. R.

Portland Cement. By A. CANTALUPI.

(Il Politecnico, 1880, p. 479.)

The Author, after defining the difference between the three kinds of hydraulic cement,—viz. the slow-setting, the hydraulic lime quick-setting, and the artificial Portland—gives the analyses of seven French and English cements. In mixing the raw materials, the proportion of clay recommended is 21 to 23 per cent., that of the carbonate of lime being 77 to 79 per cent. mixed with some other materials. If the proportion of clay were 4 or 5 per cent. higher, the product would be a species of puzzuolana which would not set in water. The presence of iron in small quantities, especially in the state of silicate, does not appear to be

injurious; on the contrary, the silicate of the protoxide of iron facilitates the hardening process. Magnesia is never found in any large proportion in good cements; but as much as 4 or 5 per cent. may be present in cements of inferior quality. Sulphuric acid and sulphur are undoubtedly injurious, especially where the cement is employed in marine constructions. The alkalies, even though they may not be absolutely essential, are yet of great assistance in the production of a good slow-setting cement. Where the raw materials contain no alkali, it is advisable to add from ½ to 1 per cent. of carbonate of soda, or carbonate of potash to the raw mixture, or their equivalent of common salt. It is believed that baryta could be substituted for the alkalies were its price more moderate.

Chemical analysis is of the greatest importance to the cement manufacturer, especially where the raw materials are variable in their composition. Although the ordinary method of chemical analysis, as employed for limestones, may be applied to cement, yet the operation may be much more rapidly performed by special methods of volumetric analysis. Great importance is also attached to trial by the sample kiln, which is useful as a means of checking the results obtained by analysis.

It is very rarely that there is found a material which possesses with uniformity the exact ingredients necessary for a good Portland cement. In many places, however, calcareous marls and argillaceous limestones are found, which require but a slight addition to change their composition to that of such a cement. Whatever may be the nature of the constituents used, it is essential that they should be reduced to an impalpable powder, either before mixing or during that operation. A wash-mill is described, and the Author then states that when a mill is used, the liquid should be passed through a very fine wire gauze before being allowed to subside. When the raw materials are in a dry state, they may be mixed very accurately by weight; but if wet they must be mixed by volume, when the results are not so accurate, and the operation requires more careful supervision. Samples of a few pints each should be taken every quarter of an hour from the wash-mill; these are analysed from time to time, or are dried and burnt in the sample kiln. When any error in the composition is detected, it should be corrected at once. The solid matter settles in tanks or "backs," and the storage in the whole of the "backs" should equal fifty-five to sixty-five days' product of the works. When the deposit is sufficiently stiff to be removed with a spade, it is dried in the open air, where the climate is favourable, or on hot plates where fuel is cheap. These plates may be heated with waste heat from coke ovens. Some manufacturers believe that heating the "slip" to 80° or 100° Centigrade improves the equality and facilitates the uniform burning of the cement.

Although the wet method of mixing the raw materials is that generally in use in France and England, yet the dry method, which, according to Lipowitz, is frequently employed in Germany, possesses many advantages.

The kilns used in France are of the same shape as those in England; the consumption of coke is estimated as $\frac{1}{8}$ to $\frac{1}{3}$ of the weight of the burnt cement. In choosing the coke, care must be taken to select that which is free from sulphur, as sulphur acts injuriously on cement. A modification of Hoffman's kiln has been used for burning cement, and the Author is of opinion that Siemens' system might be advantageously applied to the same purpose. On leaving the kiln, the cement clinker is first broken into pieces of a moderate size, and then passes into the mills. Each pair of millstones requires from 6 to 8 HP., the runner revolving from a hundred to a hundred and twenty times a minute. For every three pair of stones in motion, one will usually be under repair. From 12 to 15 tons of cement may be ground with one pair of stones in twelve hours.

Analyses of light and heavy cements are given and are accompanied by tests extending over three months of samples gauged 2 parts of sand to 1 of cement. These tests appear, however, to have been made with briquettes of a form long since abandoned by English and by German engineers.

W. F. R.

Foundations of Collonges Bridge.

(Notices on the Designs, Models, and Works collected by the Ministry of Public Works of France. Melbourne Universal Exhibition, 1880, p. 13, 4 woodcuts.)

The Rhone is very much contracted where the bridge crosses it, and rising 26 feet in flood time, flows with a velocity of $16\frac{1}{2}$ feet per second. It was accordingly necessary that the bridge should be erected without any support being placed in the river, and cross it in a single span. As the banks on each side are high, and the road could therefore be placed at a high level, the arch, which is of stone, has been made semicircular with a span of $131\frac{1}{4}$ feet. The abutment on the right bank rests on compact rock, which has such a dip that the other abutment had to be built on gravel overlying the rock, and was founded 19 feet 8 inches below the lowest water level so as to be secure from scour. An iron caisson, sunk by means of compressed air, was adopted for constructing the foundation of this abutment, and it served also as a support for the centering on that side. The working chamber was $6\frac{1}{2}$ feet high, and it alone contained the compressed air, with the air chambers fixed below its ceiling. A rectangular vertical shaft, 9 feet 4 inches by 3 feet 9 inches, communicated with the working chamber. The shaft was divided across into three compartments; the central compartment contained the ladders and the compressed-air pipe, and the side compartments furnished passages for the ascent and descent of the tubs. The chambers and shaft were so arranged that they could be taken up when the masonry in the caisson was completed. The advantages of these arrangements

are, that as few workmen as possible are placed under compressed air; that the egress from the working chamber is easy; that the passage of the material in or out of the chambers produces no appreciable change of pressure; that the air chambers have not to be moved; and that the shaft, not being exposed to pressure, was cheaply constructed, and could be easily lengthened, as the caisson was lowered, so as to keep above water. The building of the abutment up to low-water level cost £3,200; and, including the lowering of the caisson, occupied two months.

L. V. H.

On the Discharge of Water through Sluices and similar Orifices.

By K. R. Bornemann.

(Der Civilingenieur, 1880, col. 297.)

The first part of the Paper treats of the flow of water through submerged sluices, and the Author gives the results of an extensive series of observations made by himself with a view of determining the coefficients of discharge for such cases. The experimental sluices were made by placing a flat board across a parallel trough, the board resting against a strip on each side, the bottom of the opening being formed by and flush with the bottom of the trough. The height of the opening was varied by raising or lowering the sluice-board, and three different widths of troughs and sluices were used. In experiments 1 to 16 the trough was 1·135 mètre wide (44·7 inches), and the clear opening 1·006 mètre (39·6 inches) wide; in experiments 17 to 44 the trough was 0·544 mètre (21·42 inches), and the opening 0·520 mètre (20·47 inches) wide; and in the final series 45 to 63 the trough measured 0·802 mètre (31·75 inches) wide, and the opening 0·774 mètre (30·47 inches) wide.

In the above experiments weir boards were inserted in the trough about 11 feet 4 inches below the sluice, so as to pond up the tail water sufficiently to submerge the issuing stream.

Let Q = quantity of water discharged in cubic mètres per second;
a = height of opening;
b = breadth of opening:
h_1 = height of surface of head water above top edge of opening;
h_2 = height of surface of tail water above top edge of opening;
k = head due to velocity of approach of head water;
μ = coefficient of discharge;
} mètres.

Then $$\mu = \frac{Q}{a\,b\,\sqrt{2\,g\,(h_1 - h_2 + k)}}.$$

g being the acceleration due to gravity.

The effective head $(h_1 - h_2 + k)$ varied from 21 millimètres to 231 millimètres (0·83 to 9·09 inches).

The Author endeavours to find an empirical formula from which μ can be calculated so as to agree with the experiments. He tried successively eleven different formulæ, and determines the coefficients in each case from the experiments by the method of least squares. The two formulæ which give the most satisfactory results for submerged discharge are—

$$\mu = \alpha + \beta \frac{\sqrt{a}}{h_2 + \frac{a}{2}};$$

$$\mu = \alpha + \beta \sqrt{\frac{a}{h_1 + \frac{a}{2}}} + \gamma \frac{1}{\left(h_2 + \frac{a}{2}\right)\sqrt{b}}.$$

With the experimental sluices he finds as the most probable values of the coefficients for the whole sixty-three observations:—

For the first formula $\alpha = 0{\cdot}54138$; $\beta = 0{\cdot}14965$.

„ second „ $\alpha = 0{\cdot}43479$; $\beta = 0{\cdot}25666$; $\gamma = 0{\cdot}031212$.

The Author also gives some experiments on submerged discharge communicated to him long ago by Weisbach. In these the trough was 0·363 mètre (14·29 inches) wide, and the opening the same, there being no side strips. The bottom edge of the sluice was also bevelled off on the tail water side. The conditions of these experiments vary too much, and their number is too few to deduce reliable formulæ from them.

This part of the Paper also contains a critical examination of some formulæ proposed by Linnenbrügge, and published in 1879 in the "Civilingenieur." These formulæ the Author considers unsatisfactory.

The second section of the Paper deals in similar manner with the best extant observations on free discharge from sluices; the data used being the experiments by Weisbach, by Boileau, and by Lesbros.

The empirical formulæ for the coefficient of discharge are as follows: the head to the *centre* of the opening being h, and the clear height and width a and b as before, all in mètres.

For sluices built across a trough 0·9 mètre (35·4 inches) wide, the opening reaching the whole width, and the bottom being flush, along the top of opening only, for heads to 0·580 mètre (22·8 inches)—

$$\mu = 0{\cdot}5805 - 0{\cdot}01898\sqrt{\frac{a}{h}} + 0{\cdot}00144\left(\frac{1}{a}\right).$$

For sluices 0·364 mètre (14·33 inches) wide, and of a similar construction, but with the lower edge of the sluice rounded, and with low heads—

$$\mu = 0{\cdot}8624 - 0{\cdot}2194\sqrt{\frac{a}{h}} + 0{\cdot}00219\left(\frac{1}{a}\right).$$

For sluices 0·6 mètre (23·62 inches) wide, in which the bottom and sides of the opening are distant from the sides of the trough, so that contraction takes place all round, for heads to 1·800 mètre (5 feet 11 inches)—

$$\mu = 0{\cdot}5732 + 0{\cdot}01355\sqrt{\frac{a}{h}} + 0{\cdot}02109\sqrt{\frac{1}{a}}.$$

For sluices similar to the last, but with guide strips all round the opening, 5 centimètres (2 inches) from the edge, for heads to 1·800 mètre—

$$\mu = 0{\cdot}4488 + 0{\cdot}06293\sqrt{\frac{a}{h}} + 0{\cdot}5122\,\frac{b}{2\,(a+b)}.$$

The Author remarks upon the great variation which the above coefficients show, and considers that till a much greater number of systematic experiments have been made, the use of sluices for gauging water is only permissible in those cases in which the conditions and dimensions are within the limits of those of the present experiments.

The third section of the Paper discusses the experiments by Poncelet and Lesbros on the discharge through orifices in thin plates. Retaining the notation as in the second section, the Author finds:—

The rectangular orifices 0·200 mètre (7·87 inches) wide, and with contraction all round; for heads up to 1·800 mètre (5 feet 11 inches)—

$$\mu = 0{\cdot}5951 + 0{\cdot}01360\sqrt{\frac{a}{h}} + 0{\cdot}0008844\left(\frac{1}{a}\right).$$

And for similar orifices 0·020 mètre (0·787 inch) wide—

$$\mu = 0{\cdot}6262 + 0{\cdot}003291\sqrt{\frac{a}{h}} + 0{\cdot}0002063\left(\frac{1}{a}\right).$$

For openings 0·200 mètre (8 inches) wide, but without contraction along the bottom edge—

$$\mu = 0{\cdot}5074 + 0{\cdot}02126\sqrt{\frac{a}{h}} + 0{\cdot}3958\,\frac{b}{2\,(a+b)}.$$

For orifices 0·200 mètre wide, with contraction along the top and bottom, but not at the sides—

$$\mu = 0{\cdot}6550 + 0{\cdot}03611\sqrt{\frac{a}{h}} - 0{\cdot}07884\left(\frac{a}{a+b}\right).$$

For orifices fitted with a trough-shaped mouthpiece in front, and contraction at the top and sides, but not at the bottom—

$$\mu = 0{\cdot}6945 - 0{\cdot}1364\sqrt{\frac{a}{h}} + 0{\cdot}005651\,\frac{b}{2\,(a+b)}.$$

For similar orifices, with contraction at the top and the bottom, but not at the sides—

$$\mu = 0{\cdot}6967 - 0{\cdot}1033\sqrt{\frac{a}{h}} - 0{\cdot}06244\,\frac{a}{a+b}.$$

An appendix to the Paper examines the formulæ given by Weisbach and Grashoff for correcting coefficients of discharge for partial or incomplete contraction: the Author finds that these all fail when used beyond the limits of the observations from which they were determined.

W. P.

On the Compression of Air by the Direct Action of Water.

By J. P. Frizell.

(Journal of the Franklin Institute, vol. xc., p. 145.)

Ten years ago, Mr. Frizell was led to consider the mode of compressing air for mechanical purposes, by causing it, in the form of minute bubbles, to be carried downwards in a current of water, and lodged in a receiver, by changing the direction of the current from vertical to horizontal. An experiment was made in a pit at St. Paul, Minnesota, 6 feet by 14 feet, and 36 feet deep, and drained by a pipe opening into the river. A descending shaft or conduit, 15 inches by 30 inches, of wood, was constructed at one side, and an ascending shaft, 2 feet by 4 feet, at the opposite side—larger than the other, that the water might be returned to the surface with little loss of head. The shafts were connected at the lower end by a horizontal chamber, lined with zinc, having the capacity 71·19 cubic feet.

The water was let fall over a weir, 5·56 feet in length, into the descending shaft. The fall was measured by the difference of the levels in the two shafts. The readiness with which water breaks into foam is familiar to all, as well as the fact that foam is simply water impregnated with air in minute bubbles. The velocity of fine bubbles of air rising in water was found by trial to be about 9 inches per second; this may be taken as slip, and causes a loss. There is another loss, in the fall at the entrance required to impregnate the water with bubbles—about one foot; and still another loss in the resistance to movement, which, at 5 feet per second, amounted to about 1 foot.

In the first experiment, the fall was 4·07 feet; the depth on the weir, 0·63 foot; quantity of water, 9·45 cubic feet per second; pressure of air, 27·58 feet of water. Power of 1 cubic foot of air:—Admission (27·58 × 62·3 lbs. =) 1,780½ foot-lbs., with expansion $\left(\frac{1,780\frac{1}{2}}{2} \times \frac{27\cdot58}{34} = \right)$ 747·8 foot-lbs.; sum, 2,528·3 foot-lbs. Velocity of water in ascending shaft, 1·18 foot per second. Time of filling the air-chamber, 2·583 minutes; air per minute $\left(\frac{71\cdot19}{2\cdot583} = \right)$ 27·60 cubic feet. Power of air accumulated per minute, 2,528·3 × 27·60 = 69,781 foot-lbs.; power of water expended per minute, 4·07 × 9·45 × 60 × 62·3 = 143,780 foot-lbs.; efficiency 48½ per cent. The highest efficiency obtained was 52 per cent.

The Author deduces from theoretical considerations that, in an apparatus designed and proportioned under good practical conditions, an efficiency of from 75 to 80 per cent. may be expected.

D. K. C.

Loss of Pressure in Transmitting Power to a Distance by Compressed Air. By E. Stockalper.

(Revue universelle des Mines, vol. vii., pp. 257-281.)

As acting Engineer-in-chief at the Göschenen or northern end of the St. Gothard Tunnel, the Author availed himself of the opportunity to make practical trials upon the above subject, on the great length of air main and at the high pressures of air employed for the execution of the work. The air main consisted of cast-iron pipes, 7·87 inches diameter, extending 15,100 feet or 2·86 miles in from the tunnel mouth; and then of wrought-iron pipes, 5·91 inches diameter, extending 1,700 feet or 0·32 mile further; all had flanged joints, bolted together, with an india-rubber ring between. The velocity of the compressed air through the main, or the volume delivered per second, was ascertained by counting the strokes of the compressors, their delivery per stroke having previously been determined. The pressures in the air main were observed by means of Bourdon gauges, which could be read to $\frac{1}{20}$ atmosphere. The observations were made while three different conditions of steady flow through the main were continuously maintained for about half an hour each, by altering either the working of the compressors or the discharge through the cocks at the inner end of the main. Reduced to atmospheric pressure and a temperature of 0° C. or 32° Fahr., the volumes of air flowing through the main under the three conditions were 33, 22, and 18 cubic feet per second. The results of the observations are shown in diagrams, and in the accompanying Table.

OBSERVATIONS on LOSS of PRESSURE in COMPRESSED-AIR MAIN at ST. GOTHARD TUNNEL, 17 December 1878.

Condition of Flow.	Volume of Air per second, reduced to atm. pressure and 32° F. temperature.	Air Main. Length.	Air Main. Diameter.	Darcy's values for Coefficient a.	Mean Temperature inside Air Main.	Mean Density of Compressed Air. (Water = 1·00000.) δ	Volume per second of Compressed Air at mean density δ. q	Observed Pressures. At Mouth of Tunnel.	Observed Pressures. At 15,100 feet from tunnel mouth.	Observed Pressures. At 16,800 feet from tunnel mouth.	Actual Loss of Pressure.
	Cub. Feet.	Feet.	Ins.	a	Fahr.	δ	Cub. Ft.	Atm.	Atm.	Atm.	Atm.
I.	33·056	15,100	7·87	5·7855	70°	0·00650	6·534	5·60	5·24	..	0·36
		1,700	5·91	25·3195	80°	0·00603	7·063	..	5·24	5·00	0·24
II.	22·002	15,100	7·87	5·7855	70°	0·00514	5·509	4·35	4·13	..	0·22
		1,700	5·91	25·3195	80°	0·00482	5·863	..	4·13	4·06[1]	0·07
III.	18·364	15,100	7·87	5·7855	70°	0·00449	5·262	3·84	3·65	..	0·19
		1,700	5·91	25·3195	80°	0·00423	5·580	..	3·65	3·54	0·11

[1] There was probably some error in the observation of this pressure, making the loss too small.

Considering Darcy's the best of the many formulæ and tables for the flow of water through pipes, owing to their close correspondence with observed results, as well as to their simple form and convenience for calculation, the Author investigates their adaptation to the case of air; and demonstrates, on assumptions which he justifies, that the theoretical loss of pressure in air mains may be expressed, as in water mains, by the formula

$$J = a\, Q^2\, \delta,$$

where J is the loss of pressure, that is, the loss of head in mètres height of water column, for each mètre forwards along the main; δ is the mean density of the compressed air, taking water = 1; Q is the volume of compressed air at the mean density δ, flowing through the main per second, in cubic mètres; and a is Darcy's coefficient for water, deduced from his experiments. This coefficient is a function of the pipe diameter D, and is given by the empirical formula

$$a = \frac{3{\cdot}2423}{D^5} \times \left(0{\cdot}000507 + \frac{0{\cdot}00001294}{D}\right).$$

A table is reproduced of sixty-eight diameters, ranging from 0·01 up to 1·00 mètre (0·39 up to 39·37 inches), with the corresponding values of the coefficient a for water, ranging inversely from 58,395,000·0 down to 0·00168275, and passing through unity at a diameter of about 0·28 mètre. In other words,

the loss of pressure in an air main may be calculated on the supposition that it is water instead of air which is flowing through the pipe at the same velocity; and the loss so ascertained for water has then only to be reduced in the proportion of the relative densities of the air and of water, the Author's experiments having satisfied him that for all practical purposes the same coefficient a may be applied for air as is given by Darcy for water.

For English dimensions, the above formula from Darcy becomes

$$j = \frac{1}{2871 \cdot 0667}\, a\, q^2\, \delta = 0 \cdot 00034831\, a\, q^2\, \delta,$$

where j is in lbs. per square inch per foot run, and q is in cubic feet; while δ remains unaltered, and the same coefficient a is also preserved, in order that it may be obtained direct from Darcy's table on reference to the corresponding diameter expressed in mètres.

The calculated results arrived at by this formula vary however from 25 to 58 per cent. in excess of the observed actual loss of pressure given in the foregoing Table; the discrepancy is ascribed by the Author to certain disadvantages inseparable from the circumstances under which his experiments were made. A still greater excess marks the calculated results, which he also tabulates for comparison, from the formulæ of Girard, D'Aubuisson, Pecqueur, Morin, Arson, and Weisbach: confirming Professor Colladon's experiments in 1852, which showed that the coefficients adopted were about twice too high.

The temperatures inside the air main at various points of its length were observed on several different days, the velocity of flow varying from 13 to 39 feet per second, and the pressure from 3 to 6 atmospheres. They were found to remain practically constant for each individual point, and to be about 3° C. or 5° Fahr. below the constant external or tunnel temperature[1] at that place.

A. B.

On the Construction and Working of Ship Canal Locks.

By Ashbel Welch.

(Trans. American Society of Civil Engineers, vol. ix., p. 293.)

The object of this Paper is to show that by means of steam, and with proper designs, the locks of the largest ship canals can be

[1] Supplementing his previous elaborate articles on the "Influence of Temperature in Tunnelling through High Mountains" (*vide* Minutes of Proceedings Inst. C.E., vol. lxii., pp. 399–407), Dr. Stapff has now collected and represented graphically (Revue universelle des Mines, vol. vii., pp. 621–626, and plate 26) the principal results of his temperature observations in connection with the St. Gothard tunnel. The striking correspondence between the several temperature curves and the mountain profile over the line of the tunnel is palpable from a glance at his instructive diagram.—A. B.

worked with ease and rapidity, and therefore that "deep cuts," involving narrowness, danger from floods, and great expense, are wholly unnecessary.

In 1868 the Author applied steam power to the locks of the Delaware and Raritan canal, and at once increased their capacity for traffic, and therefore that of the canal, by 50 per cent. The engine has two cylinders, 6 inches diameter, 12 inches stroke, and works a 3-feet drum actuating a 1-inch wire rope, which passes over rollers along the face of the lock, and round sheaves above and below. To this rope the boats are attached, and hauled in and out, two at a time. The engine also raises and lowers the valves, opens and shuts the gates, and in one case works a swing bridge.

For large locks (*e.g.* 600 feet by 80 feet) the Author proposes to admit and take off the water by channels the full width of the length of the lock, the water entering and leaving the lock by a number of small sluiceways through the walls at right angles to the axis. This water should, if possible, be supplied not from the reach above, but from separate reservoirs. There will thus be two waterways at right angles to each other, one longitudinal for the passage of vessels only, and one transverse for the passage of water only. This avoids the expense of maintaining the paddles in the lock gates, and all the risks attending longitudinal currents. The canal should be widened above and below, and the approaches to the lock should be bounded by floating pontoons, not by fixed walls. The height of lift may be varied as required, up to 30 feet; a lift of 33 feet has been worked for twenty-five years with ease and safety. The whole space below the walls and water-space should be piled, and then covered, first with 2 feet of best concrete (laid on 2 feet of gravel if the subsoil should be clay), and then with a transverse layer of 18-inch timbers, the interstices filled with concrete. This should be covered longitudinally with 12-inch timbers under the walls, and 4-inch white pine planking under the water-space, this floor taking the place of the invert used in England. Wood and cement together hold water better than either separately: the cement stops cracks, knot-holes, &c., in the wood, while the wood does not allow the water to reach any defect in the concrete. This floor should be fastened to the foundation timbers with tree-nails, not spikes, which have much less holding power. The outside of this timber and concrete platform should be carried on a concrete or masonry wall, 4 to 6 feet thick and 6 to 20 feet deep according to the ground. At the ends this wall should lie immediately below the sills; and it should be protected by 4-inch sheet piling at the side from which water may come. Wooden or iron sills should be used, not stone, in order that the continuity of the floor may be absolutely unbroken. A "guard-gate," hinged to the inner end of the gate floor, lies flat in a recess of the floor, but can be raised at any time, if it is required to exclude water from the lock.

On this platform the main walls of the lock are to be built. For

a 30-feet lift and 30-feet depth, giving 60 feet from bottom to top of water, the thickness should be 40 feet at bottom and 20 feet at water surface. This is admitted to be excessive, but the wall is unsupported at the back, which is occupied by the water channel. The wall to batter 17½ feet at the back, and 2½ feet in front. No cut stone to be used; the face to be made of good rubble carefully grouted with best cement, and covered with 4-inch or 6-inch planking of soft timber, which, below the upper surface, will last indefinitely. The water to be admitted through ten sluiceways with fan-tailed openings, each 8 feet by 12½ feet high, and covered by sluices of iron or wood. These to be worked up and down, upon vertical screws of 2 inches pitch, by hydraulic engines, or quick-running ropes from the steam-engine; and the sliding surfaces to be all of wood. The outlet sluices may be revolving valves, 8 feet by 12½ feet high, with semicircular top, opened and shut by ropes from the engine. The sluiceways to be floored with hardwood planking, having a layer of mortar between it and the ordinary floor-planking.

The gates to be of timber throughout, and the hollow quoins also of timber, which gives much less friction than stone or iron. The gates should not be supported by rollers, but by an air chamber whose buoyancy can be regulated, or by a counterweight at the end of a balance beam. They are to be opened and closed by means of a lever, worked by a rope from the engine.

It is proposed to haul ships, maximum weight 40,000,000 lbs., in and out at a speed of 3 feet per second, and for this it is estimated that a 3-inch rope will be required, coiled round a 9-feet drum. This rope should be 5,000 feet in length altogether, and the outer parts, which never pass over the drum, should be flattened out to 12 inches by 2½ inches, and acted upon by brakes, to stop or hold a ship. As the engine only does one thing at a time, it is calculated that two cylinders, 24 inches diameter and 42 inches stroke, making sixty revolutions per minute, with 50 lbs. effective pressure, will be sufficient for the work. The crank-shaft pinion to drive a "working shaft," at one-third the engine speed, and from this shaft the rope-drum, gate-ropes, &c., to be worked by clutches. Each rope must be separate, endless ropes and friction not being reliable.

Breast lines, for preserving the ship's direction, should be operated by the engine, through travelling frames moving in a pit parallel to the lock wall, and worked by endless ropes after the manner of the travelling cranes at Crewe. The engine should be near the head of the lock, on the side where the hauling cable and inlet gates are, and close to a tube conveying the power to the opposite side. It should be wholly under the control of one man, who works all the different levers in an elevated box like a signal cabin. The engine should have provision for raising the guard-gate if required, for lifting out and replacing the main gates, &c. For this a single extra drum will be sufficient.

Though the above design contemplates rope-gearing, it is admitted that hydraulic gear might be better. The time occupied in locking a ship through is calculated at twenty minutes. The cost of the lock, 600 feet by 80 feet, and 30 feet lift, is estimated at £1,600,000, and the annual cost of maintenance at £50,000. This cost must in each case be compared with that of a "sea-level" canal. In general a lock will be much cheaper, and will enable money to be spent in making, instead of a narrow and deep cut, a broad and safe canal, in which the higher admissible speed will more than counterbalance the time spent in locking.

W. R. B.

Regulation of the River Danube in Hungary. By J. SEEFEHLNER.

(Deutsche Bauzeitung, 1880, pp. 369 *et seq.*)

The report deals only with the regulation of the Danube in the immediate vicinity of Budapest, and the projects that have been prepared for the improvement of the navigation through the so-called "Iron Gates," between Old Moldowa and Orsova. The length of river selected for regulation was about 6 miles, and may conveniently be divided into three equal sections, as follows:—In the first, or upper section, the extreme breadth is about 1,400 yards, divided into two branches by a large island, and uniting again at the site of the present Margarethen bridge,[1] having a breadth just below it of about 850 yards. At the lower end of the second section, that is, at the foot of the Blocksberg, the breadth contracts to 300 yards; and at the end of the third, or last section, it widens again to about 1,000 yards. At this point a large island (Csepel) divides the river into two very unequal arms, the right being the principal one; the left is called the Soroksar branch. The reduced velocity due to the greatly increased width of the river at the end of the third section, being unequal to the discharge of the huge masses of ice set free after thaws, caused a large accumulation of ice blocks at this locality, which produced a heading-up of the water so considerable that in 1838 the flood level was raised from 20 to 30 feet, and a disastrous inundation ensued. Soon after this plans were prepared for the regulation of the river, but for want of funds nothing was done beyond the construction of some embankments and a short length of quay, until 1870, when the following project, prepared by local engineers, was submitted to and approved by an Austrian and Hungarian commission consisting of Herren von Wex, Engerth, and Mihalik.

(*a.*) Dams to be built at each end of the Margarethen island;

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xli., p. 314.

the former to divide the river into two unequal branches, the right being the greater; and the latter to be connected with the bridge just below.

(b.) The whole extent of the middle section to have quays built on each side.

(c.) The great breadth of the river at the lower end of the third section to be reduced by the construction of parallel embankments.

(d.) The Soroksar branch to be closed and provided with a sluice.

The estimate for these works was about £650,000.

With certain unimportant modifications this was the plan carried out, and by 1876 the greater part of the work was completed.

On the breaking up of the ice, however, in the spring of that year, there was still a heading-up of the water, which inundated some unprotected outlying villages. To guard against a recurrence of this the parallel dams and quay walls along the middle section were raised to 27 feet, and other necessary precautions were taken.

In spite of this, however, the general opinion was that the regulation was a failure, and this failure was attributed to the closing of the Soroksar branch of the river. Accordingly, further modifications in the design were made, but these did not satisfy the people, and the conclusion arrived at is, that the main branch at Csepel Island must be considerably deepened, in order to get rid of even a temporary heading-up of the flood waters.

The "Iron Gates" extend for about 60 miles (between Old Moldowa and Orsova), and the obstructions are concentrated at six points.

The celebrated engineer Vásárhelyi, who had for thirty years made a study of the question of improving this part of the river, submitted a project for the same, involving canals with locks.

Subsequently Herr von Wex, on behalf of the Government, and Herr Max Albin, on behalf of the Danube Steam Navigation Company, produced independent designs for a deep canal without locks; the breadth, according to Wex, to be 186 feet; depth of bed at upper end 7½ feet, and at lower end 6 feet, below low-water level; and he affirmed that the mean velocity would never exceed 11½ feet per second.

A project was also submitted in 1874 by an international commission of Hungarian, Austrian, and Turkish members, which likewise included a canal without locks, but differed from Herr von Wex's design in certain particulars. Subsequently (in 1879) the question was laid before another commission, who condemned the open canal and proposed one with double-chamber locks, the length of each lock to be 420 feet, and width of sill 66 feet. Further details of construction are given in the report, with an estimate amounting to £880,000; and as the Government has taken up the

matter very strongly, in all probability the work will soon be taken in hand.

A plan of the river, showing the regulation works and sections of the embankments and quay walls, accompanies Herr Seefehlner's report.

W. H. E.

Ice-Gate on the Danube.

(Giornale del Genio Civile, an. xviii. p. 439.)

In volume xlvi. of the "Minutes of Proceedings," p. 296, it is stated, in an abstract of a Paper on the "Effects of the Floods on the Danube regulation works near Vienna," that it was intended to adopt some contrivance to prevent the ice from passing under the caisson at the mouth of the Danube canal. In vol. lxi. p. 336, in a Paper on the "Progress of the Formation of the new regulated Channel of the Danube," it is said that "a stop-gate erected at its entrance prevents the entry of ice into the canal." The "Giornale del Genio Civile" gives an account of this work, of which the following is an abstract.

The canal derived from the river Danube, near Vienna, was designed with the double object of accommodating navigation, and of carrying off flood waters, so as to prevent ruptures in the banks of the Danube in time of inundation. This required the employment of a movable dam at the head of the canal, which should at the same time admit water and exclude ice. The ordinary sluice-gates would not effect this object. Herr Engerth conceived the idea of making use of a floating gate, under which the water would flow freely, but which would arrest the ice on the surface.

At the same time, as it is important when the water is high to be able to reduce the level of the canal, the banks of which are lower than those of the Danube, it was needful for the work in question to act as a sluice to moderate the entrance of water into the canal, and to reduce the level of the latter by nearly 2 feet. It was therefore necessary that the floating gate should be at the same time very strong, in order to resist the shocks of the ice floes, and capable of being lowered at will, so as to obtain the desired control of the water admitted into the canal.

In consequence of the small depth of water in the canal (which does not exceed 4 feet in times of low water), and of the great width of the canal, which is 164 feet, the conditions are different from those of a floating gate for a basin.

To prevent the passage of the ice under the barrier, it was necessary to avoid the ordinary form of a boat, and to make the sides of the apparatus vertical. Under these peculiar conditions the flood-gate was constructed somewhat on the principle of an iron bridge. It is formed of three iron beams, disposed at equal distances apart, and so connected as to be perfectly rigid. To provide for immersion

it is divided into five water-tight compartments, the internal divisions of which aid in the consolidation of the structure. Each of these compartments can be filled with water, or emptied, independently of the others. To this end the gate is furnished with centrifugal pumps, cranes, and all that is needful to work the apparatus. When the gate is in place, it rests by means of oak guides at one end on a granite wall, and at the other on a movable gate. This in its turn is supported by another structure, which transmits the pressure to the side wall of the canal. By setting free the intermediate gate, the first-named structure yields in its turn, and the floating gate opens, falling with the current.

The whole of this apparatus is placed at 525 feet below the head of the canal, in order to avoid the direct shocks of the ice brought down by the current of the river. To bring the gate into place it is drawn by chains attached to mooring posts. The current, which is always very strong in the winter, tends to bear down the apparatus. so that by means of the chains it is easy to fit it in the exact position required.

To prevent the gate from sinking too low when the water shallows, four supports are placed beneath, which are moved by screws, and which rest on small sheet-iron columns fixed on the bed of the canal.

Finally, to prevent any ice from passing under the gate, a sort of iron grating is applied, which rests in part on the ironwork of the gate, and in part on the paved bottom of this part of the canal.

This floating gate has been in use since 1875, but its efficacy was specially shown in 1879. Not only did it resist the ice of that year, which was the most formidable that has been seen for a century, but at the time of thaw it offered the remarkable spectacle of a canal absolutely free; while the Danube was completely full of masses of ice, and a considerable accumulation was piled up above the gate.

F. R. C.

Mississippi River Improvement.

Annual Report of Capt. MACKENZIE of the Engineer Corps.

(Engineering News, New York, 1880, pp. 283, 290.)

Improving the river from St. Paul to Des Moines rapids.—Under this head works are carried on for the improvement of through navigation; they consist of brush and stone dams, for closing side shoots and subsidiary channels, and for contracting the waterways, and also of brush and stone shore protections for caving banks. The Author enumerates the places where improvements have been made during the past fiscal year, and where they are to be made in the immediate future. Past experience has demon-

strated that the use of an ordinary dredge boat is not advantageous in cutting channels through sand bars, but for the improvement of harbours, for the removal of gravel bars, and for obtaining materials for the construction of dams and shore protections, dredges are useful, and many are required. There are only four dredges on the river, and these belong to private persons, and are of an inferior description. The report recommends that the United States should purchase a dredge, at a cost of $15,000, capable of removing all classes of material. The work done last year was of the same character as that of the previous year. The same forms of dams and shore protections were used, but with this difference, that in the dams a larger proportion of brush was used, and in the shore protections a larger quantity of rock, both of which alterations have resulted in a reduction of cost, without any diminution of stability in the structures. The supply of brush in the upper river is becoming scarce, and steps should be taken to secure a future supply by planting sand bars; meantime this material should be economised by substituting for it rock or dredged gravel in the construction of dams.

The following are the principal works alluded to in the report. In the neighbourhood of Canton the Canton and Smoot shoot dams were constructed, and the head of island No. 416 was protected from abrasion. The Canton shoot dam is 1,095 feet long, with shore protection on the island end 200 feet in length, and on the Illinois end 80 feet. The crest of the dam is 4 feet above low water. The Smoot shoot dam is 370 feet long, with 200 feet shore protection at each end. The shore protection at the head of 416 island is 1,000 feet long. The total sum expended at Canton in the year was $10,739. At Hannibal the only work done was a little dredging to furnish temporary relief at the steamboat landing. Gilbert's shoot dam is 1775 feet long, and is situated 2,500 feet below the head of Gilbert's island, with shore protections at each end. The crest of the dam was originally 1 foot below low water, but has subsequently been raised 3½ feet. The Illinois shore opposite Gilbert's island required protection for a distance of about 13,000 feet. About 10,000 feet of this work was finished in the year. The remaining works at Gilbert's island consist of 1,000 feet of bank protection at the lower part of the island; the completion of Wing dam from the Illinois shore, 700 feet in length; and the raising of Denmark island to 6 feet above the bottom of the river. The total sum expended here was $56,119.

At Slim island progress was made in closing up several side channels; $37,963 have been hitherto expended on this work.

The total amount expended on works from Des Moines rapids to the mouth of the Illinois river was $82,691, but Capt. Mackenzie recommends that $500,000 a year should be spent on this section till the works are completed.

The remainder of the report gives a short account of the works which it is proposed to carry out in the future, and also refers

to the great assistance rendered to the safe navigation of the river by the snag and dredge boat, "General Bernard." During the year, by the help of this boat, five hundred and forty-seven snags and three wrecks were removed, one hundred and twenty-two leaning trees pulled back, four thousand four hundred and twenty-one leaning trees felled, three buoys placed, eighteen steamers assisted and pulled off bars, besides other work. There are now but few snags and wrecks of long standing remaining; and, with a view to prevent their accumulation in the future, all large trees in the neighbourhood of the banks have been felled and removed.

G. C. V. H.

Improvement of the Missouri River at Nebraska.

By L. E. Cooley.

(American Engineer, 1880, p. 99.)

The works now constructed in the neighbourhood of Nebraska city, to give stability to the river banks and for the improvement of the navigation, consist of 10,374 feet (lineal) of revetment, 1,600 feet of upper bank protection, and 3,251 feet of sand fence.

At Eastport point borings showed the existence of a stratum of coarse sand and gravel at from 25 feet to 35 feet below low water, and soundings having shown the river bottom to be on this stratum, it is believed that the limit of scour is here reached.

The works at this point consist of 4,624 feet of revetment, commencing with a header extending 300 feet inland, and are constructed of mattress-work from 35 to 50 feet in width, carried out into the bed of the river from about 3 feet above low water. For the construction of a mattress, ways consisting of spars of the length requisite for the width of the mattress are laid, with one end on the shore and the other secured to a boat built for the purpose, and inclined at a slope of 3½ or 4 to 1 towards the bank. On the ways are placed poles 4 inches or 5 inches in diameter lashed together in lengths of 56 feet, and on them a layer of brush is laid with the butts outwards towards the stream; a layer of hay is then added and then another layer of brush. The plan first adopted was to sink the mattress by means of a layer of earth between two layers of hay, but it was found that earth placed on the top was sufficient in most places except in strong currents, when rock secured by iron wire was employed. The brush was at first secured in place by laying a second series of poles over the first, drawing them together with a jack and then sewing with wire, but the upper poles were soon found to be unnecessary and the brush was then sewn to the lower poles with No. 13 or 14 wire used in a shuttle. When the mattress is complete and weighted, the lashings of the boat are cast off, and the pins inserted in the

ways to keep the brush in position are drawn out; the boat is then made to oscillate, and slips away drawing the ways with it and leaving the mattress to sink to the bottom. The thickness of mattress ordinarily used is from 8 inches to 12 inches, weighing 6 lbs. to 8 lbs. per square foot, and weighted for sinking with an additional 2 lbs. to 5 lbs. per square foot. The chief points aimed at in the construction of the mattress-work are cheapness and flexibility; with this end rock, on account of its expense, is only used for sinking, where it is unavoidable, and poles are dispensed with as much as possible. In some parts of the work stitching with wire entirely took the place of poles, with the result of greater economy and flexibility. With one boat 3,000 linear feet of mattress-work were built in 10½ days, of which 700 feet of 50 feet in width occupied 2¾ days, at a cost per linear foot of 31 cents. for material and 27·7 cents. for labour.

From the experience of the works it was found that the protection of the slopes of the bank must provide for scour down to the permanent stratum, as the river was sure sooner or later to reach this depth. The bank in settling under the mattress as the toe of the slope is removed by scour appears to take a slope of 1 to 1, or 1¼ to 1, for a depth of 20 feet, gradually assuming a flatter angle until the limit of deepest scour is reached. Thus a flexible mattress is required of a width at least equal to twice the depth from the top of the bank to the limit of scour; it must be of sufficient strength to withstand the tearing action as the bank settles, and must be weighted to make it closely hug the settling bank. In some cases the mattresses are torn, in others they have been carried away bodily by the motion of the bank and found flat on the bottom of the river. At one time during a heavy rise in the river, when the bank was being rapidly carried away, a second line of mattresses, extending several feet on to the shore and overlapping the lower series, was built, thus maintaining the upper portion of the bank, while the lower mattresses were following the flow of the bank towards the river; when these had reached the toe of the slope scour was generally arrested.

A. T. A.

Maritime Establishments in the extreme East.

(Revue Maritime et Coloniale, vol. lxvi., p. 540.)

This article gives a detailed account of all the docks and arsenals belonging to public and private bodies and Governments in that part of Asia which lies to the east of India. It also gives particulars as to the machinery available at each establishment, the cost of materials, the price of labour, the dock dues, and the charges for repairing and accommodating vessels.

The annexed Table gives the dimensions of the principal docks and basins in the Chinese and Japanese seas :—

	Name of Port and Dock.	Length.		Breadth at Entrance.	Breadth at Natural Bottom.	Breadth at Bottom.	Depth of Water at the Sill at High Water.	
		Over Blocks.	Total.				At Spring Tides.	At Neap Tides.
		Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
	Paulo Penang . .	250	..	50	..	..	14 to 15	..
Singapore.	Newharbour dock—							
	Basin No. 1 . .	415	..	62	..	..	14 „ 15½	..
	„ No. 2 . .	459	..	62	81·5	..	19 „ 20	..
	Jonjong Pagar Dock Co.—							
	Victoria dock .	450	..	65	..	..	20 „ 21	..
	New dock . .	450	..	65	..	..	21	..
Hong Kong.					At exterior sill.			
	Cosmopolitan Dock Co.	460	..	92	..	72	23	21·5
					At interior sill			
	Dock in two divisions	..	..	72	..	52	..	..
	Hong Kong and Whampoa Dock Co. at Aberdeen—							
	Hope dock . .	425	433	84	98	46	23	..
	Lamont dock .	330	340	64	82	42	16	..
	At Kow Loon—							
	No. 1.	332	340	74	84·5	48	18	..
	No. 2.	205	220	49·3	62	28·4	14	..
Amoy.	Amoy Dock Co.—							
	Amoy dock . .	286	307	55(?)	61	34	17 / 16 in spring	..
	Bellamy dock .	150 to 170	180	37	..	..	12	9
	Kulangseu dock	220	245	..	67	..	11 to 12	9
Shanghai.	Farnham and Co.—							
	Hong Kew . .	350	..	75	..	..	17	..
	Pootung . . .	325	..	..	..	..	16 to 17	..
	Boyd & Co. dock	250	..	..	..	..	10	..
Nangasaki.	Tatégami dock . .	..	..	..	..	..	..	..
Yokoska.	Old Basin . . .	377	..	82	..	..	23	21
	New Basin . . .	288	..	49	..	..	17·5	15·5
	Basin now being constructed . . .	480·5	513	95	105	..	32·8	30·1

G. C. V. H.

Port of Saint-Nazaire.

(Notices on the Designs, Models, and Works collected by the Ministry of Public Works of France. Melbourne Universal Exhibition, 1880, p. 126, 4 woodcuts.)

The port of Saint-Nazaire is situated on the right bank of the mouth of the Loire. It consists of an approach channel, lined with wooden jetties, leading to two locks which open into a dock surrounded by quays. The dock and locks have been built on the site of a small bay having a mud bottom overlying rock. The foundations of the jetties and of the quays adjoining the locks were carried down to the rock by sinking masonry wells through the stratum of mud, and the upright timbers were fixed to them. The locks rest entirely upon a rock foundation. The large lock, constructed with the view of admitting transatlantic steamers, is 82 feet wide, and its sill is 24 feet below the level of high water neap tides; the other lock is 42 feet 8 inches wide, 197 feet available length, with its sill 20 feet below the same level. The dock has an area of 25½ acres, and its quay walls have been mainly formed by lining the gneiss rock, in which the lower part has been excavated, with a facing of masonry. The total length of the quays is 1,730 yards. The port is much inconvenienced by deposit of mud from the river, so that in order to maintain a proper depth in the channel and dock 465,000 cubic yards of mud have to be removed annually by pumping and dredging, at a cost of about £3,200. The total cost of the above works amounted to £325,040.

A new dock is in course of construction, and approaching completion. An entrance to this new Penhouët dock has been made by means of a lock opening out of the old Saint-Nazaire dock. It is 82 feet wide, 426 feet between the gates, and has two pairs of gates, pointing opposite ways, at each end, so that the level of the water in the dock may be adjusted as desired and the influx of mud kept down. The dock is 3,600 feet long and 750 feet broad along its widest parts, and has an area of 55½ acres. The site of the dock being traversed by the valley of an ancient watercourse, with banks of granite and gneiss, and filled up with the alluvium of the Loire, the construction of the quay walls across this valley was attended with unusual difficulties, having to be founded on a slope of varying depth. At the bottom of the valley the depth in some places was as much as 100 feet, so that at this part wooden staging was adopted instead of a stone wall. When the depth of mud exceeded 13 feet the quay walls were built upon pillars, sunk down to the rock in the form of masonry wells, filled in solid when in place, and connected by arches on the top. The sloping rock had to be excavated under the bottom of the masonry wells, so as to afford a horizontal bed on which they could rest upright and secure. A description and drawings are given in the article of the manner in which the operation was conducted by the aid of timber inserted under the unsupported side of the well

as soon as the other side touched the rock. Where the slope of the rock was considerable it was found advisable to sink two smaller pillars in line, in place of one, for the purpose of diminishing the rock excavation, and then build up the space between them with masonry. This method, however, was attended with difficulties, both on account of the smaller wells being more difficult to sink, and also because the pillar at the back is drawn so much towards the front one in the process of sinking that it is sometimes difficult to clear out the intermediate space. The cost of the masonry in the pillars was £1 15*s.* per cubic yard. It is anticipated that the works will be completed before the close of the present year. The estimated cost of the works is as follows:—

	£
Land	71,000
Circular embankment	24,000
Earthwork	188,000
Lock	140,000
Four pairs of iron gates	40,000
Quay walls and stone packing	232,000
Movable bridge, sluicing reservoir, and hydraulic machinery	32,000
Three graving docks	120,000
Four pontoon gates for graving docks	28,000
Various works	13,000
Arrangement of lock as temporary graving dock	4,000
General expenses and contingencies	20,000
Total	912,000

A short description of the lock gates is given at the end of the article. L. V. H.

Apparatus for Tide Signals during the Night.

(Notices on the Designs, Models, and Works collected by the Ministry of Public Works of France. Melbourne Universal Exhibition, 1880, p. 248, 1 woodcut.)

The varying heights of tide after it exceeds 2 mètres, at the entrance of a port or channel, have commonly been signalled during the day time, and this has been done by a combination of balls and flags carried on yards and masts, and so arranged as to indicate the successive increments (or decrements) of mètres and fractions of mètres, but it was not until 1876 that any provision was made to give similar information during the night; in that year, however, owing to the increase of navigation on the Seine, an apparatus for this purpose was established at Honfleur. It consists of a fixed light, 1 foot 8 inches in diameter, lighting half the horizon; a catadioptric reflector occupying the other half. A cylindrical frame revolves round about the exterior of the light, and does so once in each 80 seconds. One half of this cylinder is provided with five red-coloured lenses, followed by three green-coloured lenses. Each of these lenses is mounted on vertical centres, so that it may be turned either into a circumferential position or into a radial

position. When placed radially the lenses being narrow make only slight occultations of the light, which then shines practically as a fixed white light; when, however, any one of these lenses is turned circumferentially it gives a coloured flash, which, as each lens is $22\frac{1}{2}°$ or $\frac{1}{16}$ of a whole circle wide, lasts the $\frac{1}{16}$ part of 80 seconds, or 5 seconds. It follows from this arrangement and these proportions, that when all the eight lenses are placed circumferentially, a red light is exhibited for 25 seconds, followed by a green light for 15 seconds, succeeded by white light for 40 seconds. The white light is exhibited as soon as the tide has risen to 2 mètres. When the tide has risen to $2\frac{1}{4}$ mètres, one of the green lenses is turned from the radial to the circumferential position, and a green flash is given followed by a 75-seconds interval of white light. At the $2\frac{1}{2}$ mètres level a second green lens, and at $2\frac{3}{4}$ mètres a third green lens, is put in position, exhibiting respectively 10 and 15 seconds green flashes, followed by a white light for 70 or for 65 seconds. At 3 mètres the green lenses are opened (*i.e.* placed radially) again, and the red lens, next the green, closed, exhibiting a red flash with a 75-seconds interval of white light; and then, as before, the green lenses are successively closed for each $\frac{1}{4}$ mètre above 3 mètres. Thus each red flash indicates a mètre added to the 2 mètres, and each green flash an additional quarter, so that the apparatus serves to signal every $\frac{1}{4}$ mètre, from 2 mètres to $7\frac{3}{4}$ mètres, with either a rising or falling tide. The white light has a range of $13\frac{1}{2}$ miles, and the coloured lights about 12 miles. The information as to whether the tide is rising or is falling is given by means of two opaque screens, placed near the middle of that part of the movable cylinder that does not carry the coloured lenses; these screens produce two rapid occultations in the white light when both are in position, which is the condition of things during a falling tide. One occultation indicates that the tide is rising; and no occultation signifies slack water. When the tide is below the 2-mètres level, a red-coloured shade in front of the light shows a rising, and a green-coloured shade a falling tide. A similar apparatus has been in operation at Dunkirk[1] since 1878.

L. V. H.

The Tidal Datum of Hobson's Bay. By R. L. J. Ellery, F.R.S.

(Transactions of the Royal Society of Victoria, vol. xvi., p. 146.)

The Author expresses his conviction of the necessity for fixing some common datum of reference for all tidal observations and levels sufficiently low that there should be no minus quantities, but that all should read plus or above such datum. The necessity for

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[1] The abstractor inspected the apparatus at Dunkirk last summer. It is established in the lighthouse at the end of the west jetty, and is readily shown by the light-keeper. It appears to work satisfactorily, and is easily managed.—L. V. H.

this has only recently been insisted on by the Tidal Committee of the British Association in reference to Great Britain and the European continent, and within the metropolitan area it is obviously specially important, as there are two "data" of reference, that of the War Department surveys, the old Ordnance Datum (the mean level of the sea at Liverpool), and also Trinity standard of high water springs, which is 12 feet 6 inches above the first; and there is likewise really a third datum, that used by the Admiralty, to which the river soundings are referred as the level of low-water ordinary spring tides, and which is defined as 19 feet 8 inches below Trinity standard. This was fixed in 1830, but really at the present time it is 20 feet 2 inches below Trinity, or 6 inches lower, due to the low-water ebb having been lowered 6 inches in the last half century. There is also great common misapprehension respecting the relative level of high-water springs at sea and in London, generally assumed, from observations taken in 1830, as 2 feet but which really is 5 feet, as the Admiralty annual tide tables clearly show.

The sea-level datum in Hobson's Bay had been taken from eye observations previously to January 1874, when a self-registering tide gauge (which had, however, been erected as early as 1858) was transferred from the Admiralty to the local observatory. For five years subsequently continuous daily records were kept and tabulated each week. Captain Ross's early marine survey established a datum referred to a bench mark, on the lighthouse sill at Gellibrand's Point, still used for all railway levels, &c.

Captain Cox, in 1864, after discussing two years' records of the tide, established—

Rise of tide 2·67	Lighthouse sill as	7·27	above	high-water springs.
	„	9·94	„	low-water „
	„	8·60	„	mean tide.

These were afterwards corrected, on account of some transference errors in the first, to the following relative levels, viz.:—

Rise of tide 1·67	Lighthouse sill as	5·95	above	high-water springs.
	„	7·62	„	low-water „
	„	6·78	„	half-tide.

These figures give relatively 2 feet 8 inches and 1 foot 8 inches as the rise of spring tides, whereas the Admiralty annual tide tables give the first value, viz., 2 feet 9 inches. This last level of low-water springs was subsequently adopted by succeeding marine surveyors. Numerous tide gauges were fixed from time to time by the Admiralty surveyors outside the tide-gauge house, of which there are still five, "differing more or less among themselves;" and these were used for soundings taken in reference to the alleged silting up of Hobson's Bay—"a fruitful source of errors as well as discrepancies in compared results, &c." In 1871 a law case led to an investigation of the tide returns, undertaken by the Author and Mr. A. C. Allan, who reduced all their measure-

ments to a zero 10 feet below lighthouse sill with the following results, viz.:—

	Feet above Datum.
Tide zero	0·00
Lighthouse sill	10·00
N.E. corner, dock basin	10·55
Low-water springs	2·38
B.M. niche, Prince's basin	17·69
Doorstep, Observatory	93·31

All negative readings in tidal observations or soundings are, it is alleged, thus avoided, and that no precise reference to mean tide level in earlier days was to be found.

The Paper terminates by recommending that fixed bench marks, "on the natural beds or faces of rocks *in sitú* should be established around our bay, carefully connected by accurate levelling with one another and with the tide gauge, for it is doubtful if bench marks on buildings can be assumed to afford a permanent datum."

J. B. R.

[NOTE.—It is difficult to see, after all, how negative readings will be avoided for soundings any more than in the Thames, as the low-water of springs is only 2·38 feet above the assumed datum, which would have to be lowered very much to avoid this result.—J. B. R.]

The Lavezzi Beacon Tower.

(Notices on the Designs, Models, and Works collected by the Ministry of Public Works of France. Melbourne International Exhibition, 1880, p. 221, 2 woodcuts.)

The Lavezzi rock is situated in the straits between Corsica and Sardinia, and, being in mid-channel and submerged, has been the cause of many disasters. The position of the rock is now indicated at night by the intersection of two red beams from lights placed on the islands of Lavezzi and Razzoli. By day it is marked by a stone beacon erected on the rock in 1876–7. Various difficulties attended its construction, as the rock is more than a mile from the almost desert island of Lavezzi, and 7½ miles from Bonifacio, and all the materials had to be brought from France. Moreover, the currents are very strong, the sea very uncertain, and the waves very violent during storms. The foundation consists of a solid cylindrical mass of cement concrete, 21 feet 4 inches in diameter, raised 3¼ feet above average tide level. The beacon is built of masonry set in cement, and has the form of a truncated cone, 20 feet high, with a diameter of 18 feet at the base and 13 feet at the top. The concrete generally was made in the proportions of three parts of broken stones, one of sand, and two of cement; but a larger proportion of cement was employed in exposed places. The connection of the beacon to the rock was increased by twelve iron dowels. Holes were made in the rock by borers working in cast-iron tubes; a galvanised iron dowel, having a length equal to twice the

depth of the hole, was then lowered down the tube into the hole, and the tube was filled up with neat liquid cement. As soon as the foundation had been raised to the level of the top of the rock, a segmental movable panel 2 feet high was employed for protecting the concrete from the action of the current, and for ensuring regularity of shape. The cost of the work amounted to £3,680.

L. V. H.

Report to the Minister of Public Works on the Reclamation of the Agro Romano. By the Commander O. Brauzzi.

(Giornale del Genio Civile, an. xviii. p. 430.)

The technical commission for the agrarian reclamation of a zone of the Campagna di Roma, comprised within the radius of 10 kilomètres (6·2 miles) from the Milliarum Aureum of Rome, states that it has completed its investigations, and the majority of the commission have agreed on a report, of which the following are the principal points.

While declining to make any recommendations as to details of cultivation, the commission are unanimous in the opinion that the agricultural treatment of the large area now deserted is essential to the improvement of its sanitary condition.

An attentive and minute examination of the causes which maintain the present condition of the soil in the Campagna, has convinced the commission that it will be enough, in order to lead to an agricultural change, to find the means of re-peopling this squalid desert; to apply to the area the capital necessary for its transformation, at moderate interest, including a gradual sinking fund; and to provide for the application to the soil of the manure necessary to develop a more productive return.

The majority of the commission therefore recommend—

(1.) The establishment of inhabited centres (villages) near the periphery of the zone of 10 kilomètres radius from Rome, by preference in localities accessible by existing railways. These are chiefly four, namely, near the station of Magliana, on the Civita Vecchia railway; near the estate of Quadrano, on the Naples line of railway; along the Tivoli tramway; and in the neighbourhood of the Villa Spada, near the railway from Rome to Orte.

(2.) These villages should be commenced by the establishment in each of them of a population of a thousand individuals, that is to say, about two hundred families.

(3.) To establish these villages, the government is recommended to invite the proprietors of each of the localities indicated to place at their disposition, within a limited time, 600 hectares (nearly 1,500 acres) of land for the purposes of cultivation. At the same time the government to purchase the area necessary for erecting the habitations of at least 4,000 or 5,000 inhabitants, for whose labour more land is to be from time to time provided.

(4.) Before allowing the habitation of the new villages, the government to reclaim with the greatest care the area of land assigned to each; to construct roads, paved and drained, for access; and to furnish to each an abundant supply of potable water.

(5.) It will be necessary for the State to advance to the inhabitants of the new villages the capital necessary for the breaking up of the ground, and for the construction of their cottages.

(6.) The repayment to the State to be effected by means of an annual charge on the land, to be paid in kind, as an aliquot part of the produce. For the building ground, it is to be let on lease, with the express condition of being built on; the leaseholders to pay an annual rent equal to the interest on the cost price of the land, and on the proportion of the cost of roads and drains, and a small quota by way of sinking fund, so that at a fixed time the lease may be converted into absolute ownership. Where the proprietors of the adjacent lands refuse to place them at the service of the government, they should be purchased by the State, and let on leases so conditioned as to secure a proper culture, at a moderate rent paid in kind.

(7.) To aid in the introduction of a better system of culture over the remainder of the Campagna, it is desirable that the government should find means to prevent the wild pasture of oxen over the whole Agro Romano.

(8.) The proprietors of land in the district beyond the range of the proposed village territories to be obliged to construct solid and healthy abodes for their workpeople. The amount of accommodation thus to be provided to depend on the amount of labour that may be expected to be applied to the soil, when its produce is increased by the application of the manure that will be produced on the farms.

(9.) The government to take measures for the extirpation of the reeds and scrub of the marshes.

(10.) To provide the funds for the above purposes, the administration to devise such a plan as will be least burdensome to the State.

(11.) Advances at moderate interest and with a gradual sinking fund to be made to those proprietors of the Agro Romano who request them for the purpose of erecting abodes for their workmen, or stalls for cattle, as before indicated, beyond the limits of the four proposed village territories.

The commission are of opinion that the scope of the law will be attained by the carrying out of the foregoing recommendations, which are based on the principles that the State is not to give any pecuniary aid except by way of loans, to be repaid by easy instalments within a fixed time. The exercise of any more prompt and practical measures is referred to the judgment of the administration.

F. R. C.

City Scavengering at Boston, U.S. By E. C. Clarke.

(Report of the American Public Health Association, Nashville, Tenn., 1879.)

One hundred and eighty-five miles of paved streets are swept and cleared each week; some daily, others twice a week. Macadamised streets are not swept, as by sweeping off sand and detritus their durability is much lessened, but their gutters are cleaned as required, and rubbish is picked up. The work is all done by daylight. Streets are watered before sweeping by six watering-carts. The dirt is swept to the gutters by men with birch brooms, and is thence shovelled into carts. Thirty men in all are thus employed. There are, besides, nine one-horse sweeping machines, having a revolving brush, each doing the work of eight men, and at less cost; but they cannot clean corners and depressions as a broom can. One hundred and seventy men in all, of whom eighty-two are sweepers, are employed in cleaning the streets. Asphalt is most easily cleaned; next, granite pavement. During the year, 48,059 cartloads of dirt, of 40 cubic feet each, were collected, and disposed of to fill land for streets, parks, and dwelling lots. Occasionally, a load is of sufficient manurial value to be sold for a small sum. The cost of street-cleaning for the year amounted to £17,346.

For cleaning street catch-basins, forty-three men and fourteen wagons are employed. The sludge is hoisted by means of buckets, and deposited in close-covered wagons, in which it is carried to the dumping ground, and covered with ashes. Last year, 8,766 loads were collected, at a cost of £2,700. Vaults and cesspools, from five to six thousand in number, are cleared by contract, by means of odourless excavators, at a charge of from 25*s.* to 33*s.* per load of 80 cubic feet. The excavators are air-tight, and draw the contents of the vault by the suctional force of a vacuum. The gases are destroyed by passing through a charcoal furnace as they are pumped out. Not more than one load in ten can be sold for manure.

The removal of offal—refuse food and other matters, known as swill—is effected daily in close wagons. Hotels and markets are first visited, then dwelling-houses. Ninety-six men and forty-five wagons are employed on this work. Twenty-six thousand loads, of from 3 to 4 cord feet, were collected last year, at a cost of £16,000; realising, when sold, £5,800.

In the removal of ashes, one hundred and seventeen men and fifty-eight single-horse carts are employed. When a cart is filled, it is securely covered with canvas, and taken to the nearest dumping ground. The cost for removal last year amounted to £20,300. The ashes and house dirt are used to grade streets and parks belonging to the city; but this practice is open to objections.

D. K. C.

Public Works of Chicago.

(Fourth Annual Report of the Department of Public Works, to the City Council of the City of Chicago, December 31, 1879.)

Chicago covers an area of nearly 36 square miles. There are 650 miles of streets, of which 135 miles are paved, mostly with wooden blocks. In 1879, $6\frac{7}{8}$ miles of streets were paved, of which 80 per cent. were of wood, $4\frac{1}{2}$ per cent. of Medina stone, $1\frac{3}{4}$ per cent. of macadam, $\frac{1}{2}$ per cent. of cobble stone, 6 per cent. of 3-inch oak plank, and $7\frac{1}{4}$ per cent. of cinders. The wooden pavement consists mostly of 6-inch cedar blocks, using Lakeshore gravel and composition tar as binding. The cedar-block pavement costs 1·12 dollar, or 4*s.* 8*d.* per square yard, and is estimated to last in good condition ten years.

For the construction of streets of secondary traffic, Mr. C. S. Waller, the Commissioner of Public Works, recommends the employment of macadam on the following system: Prepare the roadbed so as to be even and compact throughout with a 15-ton steam roller; let the first covering be rubble stone, carefully placed by hand, broadest surface down; cover this with 12 inches of macadam, 6 inches at a time, thoroughly rolled to bond it well; then top it with 4 inches of crushed trap rock, or some other equally hard stone, accessible and not too expensive, that will not disintegrate through the action of the weather, nor pulverise under the pressure and wear of vehicles upon it; roll this down thoroughly so as to compact and bond it well, and it will give, not only a durable, but a pleasant street to drive over. There is scarcely, it is added, any limit to the durability of such a street, with proper and timely repairs.

Street cleansing was effected by contract, at a cost of 89*s.* 3*d.* per mile for the year.

The water-supply was delivered by the North Pumping Works, at a cost of 41*s.* 5*d.* per 1,000,000 gallons, for ten years ending in 1879. In 1879 itself, the cost was only 23*s.* 6*d.* per 1,000,000 gallons, when coal cost 17*s.* 3*d.* per ton. The duty of the engines amounted to about 47,500,000 foot-pounds per 100 lbs. of coal. At the West Pumping Works, the duty amounted to 46,500,000 foot-pounds. The total quantity of water distributed daily, in 1879, was over 56,000,000 gallons, being at the rate of 118·7 gallons per head of the population. The mains, of cast iron, are from 36 inches to 4-inch in diameter. The number of meters, from $\frac{5}{8}$-inch to 4-inch, in use at December 31, 1879, was two thousand and sixty-seven; and the quantity of water measured by meter amounted to 2,312,964.750 gallons for the whole year. There was an increasing demand for water as a motor for elevators. These, a hundred and seventy-three in number, absorbed 2 per cent. of the entire quantity of water supplied to the city.

There were $322\frac{1}{4}$ miles of sewers, at December 31, 1879, of from $6\frac{1}{2}$ feet, in brick, to 1 foot in diameter, in vitrified clay, of which

the cost of construction averaged 13*s.* per foot run, including the cost of catch-basins and outlets. The sewers are flushed by water drawn from the fire-hydrants into a large wooden tank, which is conveyed by horses to the manholes. The water is there delivered into the sewers.

D. K. C.

Exploring for Water in the Neighbourhood of Lisbon.

By C. Ribeiro.

(Revista de Obras Publicas e Minas, Lisbon, vol. x., p. 408.)

The water supply of Lisbon is quite inadequate to the requirements of the city, which has a population of 275,000, and in the summer season it has often been a serious difficulty to provide the inhabitants with the quantity absolutely necessary for drinking purposes alone. This was particularly the case during the three years of great drought commencing in 1874, when the scarcity began to be felt in the month of March, and throughout October the springs which supply the Aguas-livres—the principal aqueduct leading to the upper parts of the town—became so reduced that the total discharge did not then exceed 366,000 gallons a day. The lower town was almost entirely dependent upon a few wells, and many localities remained quite unprovided for over three days at a time. To prevent the recurrence of this evil the government made arrangements with the water company for the canalization of the distant Alviella, a work of considerable magnitude, requiring some years to execute, and which is now on the eve of completion; it was, however, absolutely necessary to devise some more rapid means to provide for the pressing wants of the day, and the Author was instructed to proceed with an examination of the hydrology of the surrounding country, and to carry out such works as might be required to increase the immediate water-supply of the city.

It became apparent at the outset, that all the springs within a reasonable distance were being fully utilized in their own districts, and could not be diverted without causing much loss and inconvenience. It was also evident, that to obtain a prompt water supply, it must be derived from places readily accessible to an existing aqueduct, and at such elevation as would, if possible, render extensive pumping unnecessary. These requirements limited the area for exploration to the hilly ground lying between Porcalhota and Sabugo, which consists of calcareous beds interlaid with clay, having a dip of 15° to 30° towards the south, and rising 525 feet to 820 feet above the desired level. This district proved on examination to be the most suitable for the purpose, and it was decided to sink wells in certain selected spots, and connect them by underground galleries, driven so as to tap the water-bearing strata.

The works as executed in the valleys of Figueira, Bronco, and Lobos, are described in detail in the paper; also the character of the ground traversed, and the difficulties encountered and overcome during their progress. It is observed that although the work was carried out hurriedly to meet an urgent necessity, it was designed as a permanent means for increasing the discharge from the aqueduct. Water was met with at depths ranging from 26 feet to 33 feet, but insufficient in quantity for a continuous supply. On descending to 65 feet and 100 feet, it was found in great abundance, generally obtainable by gravity alone, through the collecting galleries into the Mota aqueduct, but the lower level waters of Figueira and Bronco had to be raised 62 feet and 98 feet respectively, by two engines of 6 HP. and 8 HP. In the Lobos valley no pumping was necessary, and although the heading had not been extended to the underside of the bed of the brook, 130,000 to 150,000 gallons of water were obtained during the twenty-four hours. The total length of piping laid down was 6,350 yards. The amount expended between 1874 and 1878, in pumping 140,800,000 gallons, was £13,300, or nearly 23*d.* per 1,000 gallons; the relative cost at first was greater than afterwards, for during the last year 44,440,000 gallons were raised at the rate of 16*d.* per 1,000 gallons.

The total supply obtained by these works is now about 330,000 gallons per day, and with a further small expenditure in extension of works, it is estimated that the quantity can be increased to 440,000 gallons. G. Kn.

Indian Water Supply.

(Professional Papers on Indian Engineering, 1880, p. 311.)

The following particulars are abstracted from a series of short articles in the Roorkee papers by officers of the P.W.D.:—

Ulsoor Water Works (by Lieut. F. J. Romilly, R.E.).

(1) This scheme was designed to supply the barracks at Ulsoor. An existing reservoir is used, and also a set of thirty-two wells near the foot of the bund, called the Dhobies Wells, the water from which is supposed to be purer (it would seem, however, to be the percolation of water from the reservoir), and is pumped by engines (10 and 12 HP.) from either source into cisterns at each of the barracks, after passing through a filter bed and pure water tank. The reservoir has an area of 124 acres; average depth, 7·68; capacity, 260,000,000 gallons. The drainage area is 3,330 acres; maximum rainfall, 6 inches in twenty-four hours, or 69,696,000 cubic feet. A residuum lodge or reservoir was constructed above this to catch silt and increase storage room. Capacity, 62,500,000 gallons; drainage area, 1,130 acres. The number of people sup-

plied is three thousand, exclusive of natives, and one thousand two hundred and fifty horses. This scheme has passed through many phases, and cost much money, being now apparently twice the size required, sufficient water being procurable from either source (Minute of Government, April 1872). The filter beds leak.

ALMORA (T. W. Ashhurst).

(2) The Almora Water Supply is collected from springs by a channel of concrete covered with stone slabs. It supplies the population of Almora (eight thousand) with two gallons per head per day; has a storage reservoir 100 × 10 × 10, or seven days' supply, and ordinary filter beds of 40 × 10 area. The cost was Rs. 21,000.

AHMEDABAD (Lieut. J. Neville, R.E.).

(3) Water first supplied by four Persian wheels, which being insufficient pumping engines (5 and 6 HP.) were erected, and fresh distribution pipes laid. Daily supply, 133,000 gallons, or 5 gallons per head per day for 25,000 people. The water is pumped into a settling tank and filtered. The total population is 111,680, only one half of those who could be supplied availing themselves of it on account of caste.

KARANDWAD.

(4) Karandwad is a town of eight thousand inhabitants, which in 1866 set up a small wind engine, 3 HP., to pump water from a well 10 feet in diameter and 35 feet deep, to a storage tank ¾ mile away. The works, like others depending on wind in the East, are not successful, and the tank leaks; there is no distribution from the storage tank, the water being drawn direct. The cost was Rs. 23,807.

ADEN (Lieut. H. Clarke, R.E.).

The rainfall here is always very scanty, and the sources of supply are: (1) Condensed Water, (2) Wells, (3) Shaik Othman Duct, (4) Tawella Tanks Supply, (5) Kussoff Valley Scheme.

(1) Condensed water is supplied from (*a*) condensers at the isthmus, (*b*) a condenser at Seerah island, (*c*) the Hydrabad, a river flat; into tanks, originally badly constructed, but now repaired. They could yield 5 gallons per head per day for 10,620 Europeans. There are other condensers, which are private property.

(2) Wells; seventy in British limits, which averaged from 120 to 190 feet deep; others in neutral territory. This water is brackish, and unfit for drinking purposes.

(3) Shaik Othman Duct; two wells, 10 feet in diameter, and 25 feet deep, worked by pumps driven by camels, delivering 24,000 gallons per twenty-four hours, into tanks at the isthmus. The water is brackish, and unfit to drink.

(4) Tawalla Tanks; probably constructed A.D. 600, to catch the

rain-water flowing down the numerous ravines from the range of hills 1,760 feet high. There are altogether fifty tanks, of which thirteen are in use, with a capacity of 10,753,690 gallons. Shield bunds have been placed above these to catch the débris brought down by floods. They are of stone and lime masonry, and supply the tanks, which are plastered excavations from 10 to 60 feet deep, all connected by covered ducts. Cost of restoration, Rs. 360,000.

(5) Kussoff Valley Lakes consist of one Shield bund and two Main bunds, erected to catch the water as it flows from the ground. No. 3 bund was filled to 28 feet in a fall of rain in September 1877, but it all disappeared in thirty-six hours' time.

INCHALKARANJI.

A town of eight thousand inhabitants, originally intended to be supplied by water pumped from the Punchganga river by wind engines, which failing, except in the monsoon, 8 HP. steam pumps were substituted, yielding ten gallons per head per day. The cost was Rs. 111,174.

SECUNDERABAD (Capt. H. C. FOX, R.E.).

The troops are supplied from two sources, the south and north water supply, from wells, the water being pumped by five engines into service reservoirs and cisterns, two of which would give a delivery of 10,000 gallons per hour if worked at the same time. The total cost is unknown.

C. J. W.

The Sewage Question. By M. AUBRY-VITET.

(Revue des Deux Mondes, Year L., p. 665.)

The Author describes the mode of purifying the foul water of the paper manufactory of Essonnes, which amounts to the daily volume of 10,000 metric tons.

The article commences by a reference to the scheme proposed by a Commission, consisting of Messrs. Belgrand, Mille, and Durand-Claye, of which an account will be found in vol. liii. of Minutes of Proceedings, p. 193, in continuation of an account given in vol. xxiv., p. 257. In that account it was stated that the Paris authorities considered that 2,470 acres of the plain of Gennevilliers were available for sewage irrigation and cultivation, but that the municipality of Gennevilliers considered that only 1,373 acres were available. The quantity of sewage diverted to irrigation in July 1876, was stated at one-sixth of the volume of the contents of the collecting sewers of Asnières and St. Ouen, the remaining five-sixths being still (at that time) discharged into the Seine. The information of M. Aubry-Vitet is of a later date. He says that as soon as the details of the scheme in question (the surveys for which were only ordered in 1875) became known, universal opposition

was encountered from the population of the districts comprised in the irrigation project. A commission, nominated by the Prefect of Seine and Oise from among the members of the Council-General of that department, protested earnestly against the plan, as being at the same time ineffectual for the purification of the Seine, and destructive of the value of the property that it was proposed to irrigate. Out of thirty-two communes, twenty-seven protested by the organs of their municipal council; and in the localities most concerned eighty thousand five hundred signatures were given to individual protests against the measure. The inhabitants of Gennevilliers ascribed the spread of fever to the progress of the works.

It was given in evidence that from the time when the sewage was first turned on to a part of the plain, the underground water line continued steadily to rise. The sand quarries in the plain were converted into bogs; the water entered the cellars of the houses in the village; it raised the level of a reservoir, constructed for the use of a large manufactory, nearly 5 feet; it obstructed a passage made under the road, and at last it made its way into the boiler furnaces of the establishment in question. The engineers of the scheme referred these disasters to the floods of the Seine. The inhabitants replied that the Seine had always been subject to floods, but that this increase in the height of the water on their subsoil had not been known before the commencement of the irrigation.

Under this opposition, the execution of the project of Messrs. Belgrand, Mille, and Durand-Claye was tacitly suspended. More recently (the exact dates are not given in the article), a modified project was brought forward, which proposed to make use only of 3,700 acres of the Forest of St. Germain for irrigation, confining the use to be made of the districts intervening between the forest and Paris to allowing passage for the high-level conduit, which was to conduct to that spot the volume of 300,000 metric tons of sewage per day of twenty-four hours.

Against this modified project M. Aubry-Vitet states that an opposition as determined as that which met the first scheme has been raised; and in this state of dispute the matter appears now to be left.

M. Aubry-Vitet then contrasts the two operations of sewage cultivation and of sewage utilisation. The first, he says, is a purely agricultural process, in which the daily dose must depend on the nature of the soil, and on the character, state, and special requirements of the several crops. The latter is a continuous operation, allowing of no variation, and in the course of which the influence on agriculture can hardly, if at all, be taken into account. For utilising the sewage of Paris, in such a manner as to give to every acre of land a much larger amount of fertilising matter than is usually supplied by the manures used by the French farmers, an area of 148,000 acres would be required, while from 6,000 to 10,000 acres is the outside of the land that would be required for the sole purpose of filtering and disinfecting the sewage.

Under these circumstances M. Aubry-Vitet describes the process

which he states to be now carried on with perfect success at the paper factory of Essonnes. The first attempts at purifying the foul waters coming from factories were made seven or eight years ago, and are described in a work by M. de Freycinet.[1] They were conducted at Lille, and were not altogether successful, but had the effect of making the administration more severe in its requirements. The plan adopted at Essonnes is as follows; it consists of two parts, viz.:—

1. Is a series of basins, perfectly water-tight, destined to allow the subsidence of the solid contents of the water. These are called basins of decantation.

2. A series of basins constructed alongside of the former, at a lower level, with permeable bottoms, intended to complete the drainage of the mud precipitated in the upper basins.

The operation is thus conducted:—

The foul water of the works is collected in one channel of from 18 inches to 2 feet in width. Alongside of this little canal, and above it, is disposed a series of circular vats containing lime water, of which the effect in causing the precipitation of organic matter is well known, and which is cheaper, and probably more rapid in its action, than sulphate of alumina. They are provided with agitators, which keep the lime in suspension, and with gauged taps, which allow of the passage of the mixture into the current of foul water in the canal. The proportion of lime is from 6 to 9 ounces avoirdupois to the metric ton of water. Slight obstacles are placed in the narrow channel, to cause more movement of the water in its passage, and thus to effect the complete mixing of the stream with the jets from the taps. It is added that the moment this mixture is effected the water loses all odour, and no longer emits any unhealthy exhalations.

From this canal the water is conducted into the upper basins, or basins of decantation; these are arranged side by side, and each measures 65·6 feet in length by 20 feet in width, and 5 feet in depth. Each of these basins serves for the "decantation" of 1,000 metric tons per day. The water enters constantly at one end of the basin, and issues from a spout at the other end. The speed is so low—not exceeding four-tenths of an inch in a second—that the precipitation is effected as readily as if the water were quite still. At the spout it is perfectly clear. This passage of 65·6 feet, at the rate of 0·4 inch per second, represents a delay of about six hours in the basin, and is enough to precipitate all the solid matter held in suspension in the water.

Little by little a slope of mud forms on the basin, which by the end of a week reaches from the bottom of the basin near the spout to the surface of the water near the place of entrance. At this point the admixture of the water is arrested. The clean water in the basin is removed by a siphon, and the mud is left exposed.

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[1] De l'Assainissement industriel; de l'Assainissement des villes. Paris, 1870.

The bottom of the basin slopes gently downwards towards the side on which the water enters. A large valve is placed at the lowest part, which is now opened, and the mud, still in a semi-liquid state, is allowed to flow out into the lower basin alongside. This is of the same area as the decantation basin, and its surface is a little below the level of the bottom of the former. The walls of the lower, or drying basin, are of masonry. The bottom is composed of a layer of slag, drained by a series of drain tiles which empty themselves into a culvert. The greatest importance is attached to the use of slag, through which the mud is said to drain perfectly without entering, or at all fouling, the same. The water escapes quite clear from the culvert. At the end of two or three days cracks appear on the surface of the mud; they enlarge and deepen, and in a week the mud has attained sufficient consistency to be removed by the spade. A small wagon is then run into the basin, on a pair of rails laid on the surface of the slag, and the mud is filled into this in the form of hard clods. The moment that it is removed the basin is ready to receive a new charge.

The clods of mud in the wagon are run out to an open drying ground at a little distance, where they dry without emitting the least smell. When filled into the wagon the mud contains 75 per cent. of water; this is reduced to from 15 to 20 per cent. at the end of three months' exposure.

The whole apparatus of precipitation basins, drying basins, drying yard, roadways and canal, occupy a surface not exceeding 5 acres, which provides for the purification of 10,000 metric tons of water in twenty-four hours.

The cost of the basins was 20 francs per square mètre, or 13·4*s.* per square yard. The cost of labour is about 16*s.* a day; the cost of the lime is not more than 16*s.* per ton. These prices are applied by M. Aubry-Vitet to the figures of the sewage of Paris, with the result that the total cost of the application of the system to their purification would be £120 per day.

It is further calculated that from each metric ton of the foul water of Paris will be precipitated from 165 to 230 grains of nitrogen, and from 300 to 385 grains of phosphate of lime. The former is worth nearly 9*d.* per pound, the latter about ½*d.* per pound. On these data it is estimated that as much nitrogen and phosphate of lime could be extracted from the sewage of Paris in a year as would be enough to manure 74,000 acres, and that the value of these two elements alone would amount to £280 per diem, leaving a possible daily profit on the works of £160.

M. Aubry-Vitet insists that the other constituent parts of the mud are not unfavourable, but rather the reverse, to the action of the nitrogen and phosphate of lime as manure. But he gives neither the complete analysis of this material, nor the actual bulk or weight of deposit from a metric ton either of the Essonnes foul water or of the Paris sewage.

F. R. C.

Cost of Planting Trees in the Paris Boulevards. By E. Bosc.

(L'Architecte, 20 Nov. 1880, p. 370.)

Owing to the nature of the soil, soot, escapes of gas, and other causes, the life of a tree in the streets of Paris does not exceed ten, or at most twelve years, and large numbers have to be planted every season to replace those decayed. The expense thus incurred is very great, and the Author suggests the replacement of the trees by glazed arcades, which would afford shelter from the sun in summer and from the rain at all times. The annexed figures, showing the cost of planting one tree, have been furnished by the Administration of Works of Paris, and are therefore indisputable:—

	F.	c.
15 mètres of excavation at 4 francs	60	00
15 mètres of vegetable earth at 4 francs	60	00
Training pole from 4 to 5 mètres high	1	50
	121	50
Average deduction of 15 per cent. resulting from letting by tender	18	23
Contract price	103	27
Pipe drainage and materials	11	15
Watering appliance (average)	2	50
Cast-iron grating round the base	46	69
Transport of the tree	2	00
Planting, including stakes	3	00
Iron corselet	8	70
Tree	5	00
Labour for planting	1	69
	184	00
Twelve years' maintenance at 1 f. 58 c.	18	00
	202	00

In round numbers, therefore, each tree costs 200 francs. There are about 103,650 trees in Paris, and as they last but twelve years, the sum of 20,730,000 francs has to be dispensed every twelve years. The Author remarks that formerly the tree and planting cost but 50 francs, and lasted as long as at present. Some extracts are given from the report of the Director of Works of Paris (M. Alphand), who is severely criticised in regard to the expense of the "rows of broomhandles, pompously decorated with the title of 'plantations,'" and the establishment is deprecated of the proposed School of Horticulture for Paris.

F. G. D.

NOTE.—In the above calculation the Author apparently supposes that everything has to be renewed once in twelve years, but this must be incorrect. The most considerable items of the original outlay, viz., vegetable earth, iron-gratings, "corselet," &c., can be used again, and the tree costs but 5 francs.—F. G. D.

On the Action of Frost on Gas- and Water-pipes.

By C. LANG and EITNER.

(Journal für Gasbeleuchtung, 1880, p. 504.)

During the winter 1879-1880 the temperature in Central Europe was not only exceptionally low, but the cold continued so long without any break that both gas- and waterworks were seriously interfered with. In December 1879 the mean temperature of Carlsruhe, situated 115 mètres (377 feet) above the level of the sea, was − 8·22° C. (18·17° F.), while the average of the preceding eighty-one years was + 1·9° C. (35·42° F.) during the same month. The lowest temperature observed was − 22° C. (− 7·6° F.) The first frost continued for thirty-three days without intermission; a slight thaw then ensued, which lasted a week, and was again followed by continuous frost for thirty-five days. Since 1829-1830 no winter had approached the last in severity, so that neither gas- nor waterworks were prepared for such exceptionally low temperatures. At the Carlsruhe gasworks there are six gas-holders of different sizes, the three largest of which are provided with small boilers for heating the water. A double system of pipes connects the top and bottom of each boiler with the gas-holder tank, and allows the water to circulate as it becomes heated. The tanks are built at different levels, so that the water can flow from one into the other. The space between the receiver and the walls of the tank is closed with boards, which are covered in winter with a layer of manure to protect the surface of the water from the action of cold winds. This arrangement had previously sufficed to keep all tanks free from ice. A slight current of water was admitted into the upper tank from the water main, the boiler heated with about 1½ cwt. of coal a day, and the warm water from the first tank allowed to flow into those below. This had usually been sufficient to keep the water of all the tanks free from ice; but in the present case, although three boilers were continually in use, yet they were found inadequate. Ice began to form in the interior of the small gas-holders, while the water outside the receiver remained several degrees above freezing point. As the ice would soon have rendered both the inlet and outlet pipes useless, measures were taken for its removal. A gas-pipe of 20 mm. (0·79 inch) internal diameter was twice bent at right angles and placed in the tank in such a manner that one of the ends passed under the edge of the receiver, and stood upright to a height of 6 feet in the water inside the gas-holder. Steam was then blown through this pipe, and in two days every trace of ice was removed and the temperature of the water raised to 10° C. (50° F.). In order to keep the water from freezing again, it was only necessary to inject steam for a few hours every third day. The boiler used was one which worked an engine of 4 HP., and the increase in the consumption of fuel was inappreciable.

4·8 per cent. of the gas-meters fixed in private houses were stopped by the frost, but were soon made to work again by the addition of glycerine or spirits of wine. As the whole system of gas-pipes lay in the frozen ground for weeks, many of the supply pipes became choked with naphthaline. In every case the obstruction could be removed by forcing air through with a force-pump.

The injurious effects of the frost were much greater on the water than on the gas supply. The ground being frozen to a depth of 5 feet, many of the supply pipes were stopped. This was accelerated by a regulation prohibiting the consumers from keeping their taps running constantly during the frost, with the object of preventing the pipes from freezing. The best method of thawing the frozen pipes was found to be the following:—The supply pipe was disconnected at its entrance into the house, and a lead or india-rubber tube of smaller diameter inserted into it, until the plug of ice was reached. Steam was then admitted into the centre tube, which was gradually pushed forward as the ice melted away, the operation being continued until the water forced its way through from the main. The cost of thawing each supply pipe in this manner was about 3*s.* 6*d.* It was found that 10 per cent. of the pipes thawed by means of steam burst, while only 3 per cent. gave way when they were allowed to thaw gradually on the return of milder weather. All the supply pipes were made of cast-iron; an experiment made with wrought-iron pipes showed that they were not injured when thawed by means of steam.

The flow of water required to keep pipes from freezing is not so great as is generally supposed. A wrought-iron pipe, 13 mètres (42·6 feet) long and 25 millimètres (1 inch) internal diameter, was kept free from ice at an external temperature of − 7° C. (19·4° F.) by running 30 litres (6·6 gallons) of water through it per hour. The water entered the pipe with a temperature of + 5° C. (41° F.) and left it 1° C. above freezing point, or at 33·8° F.

Some public taps were prevented from freezing by placing a gas flame in the hollow space beneath them.

W. F. R.

On the Construction of Pipe-lines for the Conveyance of Petroleum. By C. G. Vorslav.

(Zapiski Imperatorskavo Russkavo Tekhnitcheskavo Obschestva, Jan. 20, 1879.)

The Author commences by remarking that there exist no experiments for determining the flow of petroleum through pipes, but quotes General Haupt, of the Pennsylvania Transportation Company, who gives the formula $Q = 4{\cdot}1 \sqrt{\frac{d^5 h}{l}}$ for the delivery in cubic feet per minute of pipes d inches diameter, h feet long, under a head l feet, remarking, however, that Haupt's experience is

limited to 4-inch pipes. (The value of the coefficient for water is 4·7.)

The relative advantages of continuous and interrupted mains, where, from their extreme length, several pumping stations are necessary, are discussed, but no conclusion arrived at; and with a like result the merits of rotatory and direct-acting pumping engines, surface lines and pipes laid underground, are considered, together with the best form of joints. The prejudicial influence of variations of temperature on long surface lines is noted, and the means adopted to prevent loss from the bursting of pipes pointed out. The Paper ends with estimates of the cost of laying and working long lines of pipes, and is illustrated by nine diagrams.

The Author gives very little information derived from actual practice; hence his Paper, though interesting, will not be of much use to those engaged in laying petroleum mains.

W. A.

New Route across the Alps.

(Giornale dei Lavori Pubblici e delle Strade Ferrate, an. vii., pp. 462–475.)

The need for additional lines across the Alps is now admitted alike in France and in Italy, and the scientific writers of both countries are engaged in discussing the advantages of the competing routes. A pamphlet has been recently published by M. Chardon, a member of the French Senate, which has received much commendation in France, while it is criticised in Switzerland and elsewhere. M. Chardon alleges that the opening of the St. Gothard Tunnel will give a very great advantage to the German railways, and to the ports of Antwerp and Ostend, to the prejudice of the French ports of the Channel; and that France, in order to retain her own commerce, must hasten the construction of an intermediate line of communication, shorter and more economical than that of the Mont Cenis pass.

The line of the Simplon was originally proposed as the only remedy that could be found for the evils which, from a French point of view, were certain to arise from the completion of the St. Gothard line. After a series of discussions on the subject, it was at last brought before the National Assembly. The question was considered by that body to be so important that a special commission of Inspectors-General of Engineers was named, charged to study the most favourable point for the passage of the Alps. The Commission reported in favour of the Mont Blanc route, and their report was approved by the Superior Council of the *Ponts et Chaussées*. The duty of surveying the line was entrusted to M. Godin de Lepinay, who produced plans showing the feasibility of a line of communication by Mont Blanc. This took place in 1876. In 1879 the subject was again brought before the Chamber of

Deputies, which then voted for the Simplon route, while the Senate preferred that by Mont Blanc.

This question M. Chardon proceeds to discuss. The first point that he brings forward is, that while the St. Gothard and the Simplon routes must traverse a portion of German or Swiss territory, the routes by Mont Cenis and Mont Blanc lead directly from France into Italy. As to gradients, the writer argues that the Mont Cenis, the St. Gothard, and the Simplon routes must always remain imperfect channels of communication, requiring special engines to mount their inclines; while by the Mont Blanc route the same locomotives might run from Paris or even from Calais, to Piacenza or to Brindisi.

As to cost, M. Chardon argues that the Mont Blanc route would only cost about half as much as that by the Simplon. The capital for the first line he estimates at 79,900,000 francs; that for the second at 130,200,000 francs. The Mont Blanc route could be opened in five years, while the execution of the Simplon route would require at least ten. Finally, in the political view of the case, M. Chardon urges that the Mont Cenis line, directed on Turin, and the Mont Blanc line, pointing to Piacenza and Milan, would favour the relations of interest and of friendship between France and Italy.

The opposite point of view is taken by M. D. Colladon, who has recently published at Geneva a work intended to show the difficulty and inconvenience of the Mont Blanc route, and the advantage of an "international railway" across the Simplon. He attacks the projects of the Mont Blanc line, urging that they are so numerous that it is impossible to regard them as accordant. The most practicable of these, however, he considers to be that of Messrs. Chardon, Chabloz, and De Lepinay, which traverses the great valley of the Allea Bianca, from Dollone to Courmayeur. The length is from eighteen to nineteen kilomètres. The soil of the valleys of Aosta and of Allea Bianca is, in the opinion of M. Colladon, extremely unsuited for tunnelling, and the infiltration from the beds of the Allea Bianca and the Dora would offer great obstacles to the enterprise. The line traverses 2,300 mètres of rock, interspersed with aluminous schist, mingled with carbonates and sulphates of lime. Then follow from 100 to 150 mètres of crystalline gneiss, under which is a primary mass of the same origin. To resist the pressure of such strata it has been found necessary, in the St. Gothard Tunnel, to prop, and then to rebuild the arch, and to triple its thickness, thus involving an incalculable expense. From the bad quality of the soil the infiltration, if not always abundant, is constantly dangerous. Such difficulties, it is stated, do not oppose the construction of a line by the Simplon pass, of which the superiority both as to avoiding natural obstacles, and as to financial feasibility, is said to be unquestionable.

From a comparative survey of the two routes it is known that, while the line from Coblentz, by Mont Blanc to Milan, is 447 kilomètres long, that by the Simplon is 30 kilomètres less. Besides

this, the Simplon line is already complete for two-thirds of its length, exclusive of the tunnel, while only half the Mont Blanc line is executed. The central position of the Simplon pass, between Mont Cenis and the St. Gothard, unites all the conditions that are desired for a direct communication between France, Belgium, and England on one part, and Italy and the East on the other. Finally, the summit of the Simplon pass is the lowest of any Alpine passage, and its means of access are by far the most convenient.

Above all, the military and political features of the case appear to M. Colladon to be decisive. If the Simplon route be completed, the Italians will have a pass the fewer to guard against France than in the case of her opening a second line bearing on Ivrea and Turin; by which, according to the argument of M. Chardon, three times the number of military trains could be despatched, at double the velocity, compared with the northern route.

F. R. C.

The Pontebba Railway. By E. L.

(Zeitschrift des österreichischen Ingenieur- und Architekten-Vereins, 1880, p. 113.)

The line connects the Italian town of Udine, 358 feet above sea level, with Pontebba, 1,860 feet above sea-level, on the Tauris-Pontafel railway, near the Austro-Italian frontier. For a great part of its length (42½ miles) it runs through a country of exceedingly difficult character, necessitating the construction of twenty-eight tunnels, various heavy viaducts, and about four hundred bridges, the total cost amounting to about £1,440,000. The portion nearest Pontebba is the most expensive, for the last 7½ miles averaging over £69,000 per mile.

Diagrams are given showing the normal sections of the battering and vertical retaining walls, with tables in terms of the height and thicknesses at base and top; but in practice these had to be considerably modified. In cases where the rock was sufficiently stable, pier and arch retaining-walls were used. The battered retaining-walls are generally surmounted by a parapet 3 feet 3 inches in height, and the vertical ones by a wrought-iron balustrading, with an arrangement for allowing an expansion of ⅝ inches at every 82 feet.

A diagram of the cross-section adopted for tunnels, which was the same in all cases, is given. It is of horse-shoe form, the interior maximum dimensions being 18 feet by 18 feet.

In almost all cases the tunnels were lined, the least thickness being 1 foot 4 inches, and in instances where character of strata was unfavourable, varying from 1 foot 9 inches to 3 feet 6 inches.

The total length of curves on the line is 12¼ miles, the minimum radius being 15 chains.

The total length of tunnels (twenty-eight) amounts to 3¼ miles. The number of stations is twelve, and of the various watch guard-houses, including those at each end of stations, is seventy-five, frequent inspection of the line being necessary, there being an annual rain and snow fall of from 59 to 94½ inches, occasioning frequent land-slips. The guard-houses are elevated on an arched basement, and contain four chambers, and cost on the average £190 each.

The works in general were executed by contract. The various descriptions of masonry come under the heads of coursed and uncoursed, full and partial mosaic work. In the former class no two consecutive courses were to vary more than 2 inches in depth, the minimum to be 12 inches.

In full mosaic work the stone is of pentagonal form on face, and in partial mosaic work may be less regular. The prices paid for these various kinds of face-work were—

	s.	*d.*	*s.*	*d.*	*s.*	*d.*		*s.*	*d.*	
	3	7½	3	1½	3	1½	and	1	4	per square yard.
or	4	3	3	9	3	9	„	1	7	„ „ mètre.

(5·40, 4·65, 4·65 and 1·95 lire per square mètre respectively), in addition to 17 lire per cubic mètre (10*s.* 5*d.* per cubic yard). Where scaffolding was necessary, an additional price of 8½*d.* per cubic yard (1·14 lire per cubic mètre) was allowed. In excavation for foundations the prices varied from 1*s.* 5*d.* to 2*s.* 11*d.* per cubic yard (2·40 to 4·65 lire per cubic mètre), exclusive of timbering, which was paid for by the square mètre.

The workmen employed were generally from the north of Italy, the Piedmontese being the best stone-setters and tunnel-men, the Friaulese excelling in ashlar, and the Lombardians in brickwork, whilst the Romagnians and Padovians made the best excavators. The Author gives a detailed description of the circumstances and difficulties attending the erection of the viaduct Ponte di Muro.

At the end of the summer of 1878, the whole line was completed with the exception of the Ponte di Muro. In Italy it is necessary that the designs for all bridges of more than 32 feet 9 inches span should be submitted to the Minister of Public Works for approval. Three designs for this construction were sent in, but in consequence of the delay in the acceptance of the one finally decided upon the actual work was not commenced until the end of September 1878.

As it was impossible to erect the permanent iron girders by the time appointed for opening the line, it was determined to make the timber staging used for erection sufficiently strong to carry on the railway traffic temporarily, and at the same time to be constructed in such a manner as to permit of the girders ultimately being got into their place without arresting the traffic. With this object the rail level on the staging was made 2 feet higher than the intended permanent level.

A contract was entered into with a firm at Castellamare for the

erection both of the staging (to be completed by the commencement of July, 1879), and also the supply and erection of the girders which were to be in their place and finished by the end of November. Owing, however, to the non-delivery of the ironwork, this staging had to serve until May 1880. This was rendered possible only by the fact that there were no floods of importance during the interval. On the 12th of July, 1879, the staging was tested with seventeen heavily-laden ballast wagons and two locomotives running over at a rate of 12½ miles per hour, the result being a temporary deflection of ¾ inch, and a lateral movement of 1¾ inch. During the time that the staging was in use the 75-ton engines made by Sigl, of Vienna, were not run, the traffic being worked by smaller ones of 58 tons run at a low speed, and all trains were stopped before crossing to take up an attendant, who again alighted after crossing. On the 20th of May, 1880, the iron construction was completed; the work connected with the operation of changing the traffic from the provisional to the permanent structure was principally performed in the course of one night, and necessitated the suspension of three trains only. The girders were proved with two Sigl engines and tenders weighing 75 tons, and a smaller engine of 58 tons; with this as a running load, the temporary deflection was 1¼ inch, and lateral movement ¼ inch.

There are five sheets of diagrams accompanying the original Paper, and detailed prices of the Ponte di Muro viaduct and the San Rocco tunnel.

D. G.

Railways in the North of Portugal. By F. M. de Sousa Brandão.

(Revista de Obras Publicas e Minas, Lisbon, vol. xi., p. 145.)

Two important lines have recently been constructed by the State in the north of Portugal, viz.:—the Minho railway, commencing at the town of Oporto, and passing northwards, over an interesting country parallel to the general course of the seashore, to Valença, where it terminates, having a total length of 90 miles; and when the river Minho has been bridged, it will be placed in direct communication with the railway system of Galiçia, in Spain. The other, the Douro railway, starts from the previous line at Ermizinde, 5½ miles from Oporto, and branching off in an easterly direction, follows the valley of the river Douro. At present it has only been completed up to Pinhão, a distance of 68½ miles, but it is proposed to extend it to Barca d'Alva on the Spanish frontier. These two lines will form the main arteries of communication through the provinces of Minho and Tras os Montes, and are on the 5 feet 5¾ inches standard gauge of the country.

During the progress of the works, the Government decided that

an examination should be made, of the whole subject of providing the best means of communication, between the interior of the provinces and the new railways, with the view of developing their traffic. This was entrusted to the Author, and from his reports it appears that the public highways constructed in recent years through this mountainous country have cost from £1,500 to £2,200 per mile; and he remarks that if others were now to be made along the valleys, at right angles to the main lines, they would cost as much, and produce no direct money interest on the capital expended, whilst a continual outlay would be incurred to keep them in repair. To substitute them by ordinary gauge railways, it was found, would involve an expenditure which neither the present nor probably the future requirements of the district appeared to warrant, and therefore the conclusion was arrived at that a system of mètre gauge lines, with roadway facilities to the more important places, would best answer the purpose. With this view many routes were examined, and finally the following lines were selected and recommended for construction.

Tua to Mirandella and Bragança, to commence near the mouth of the river Tua, 7 miles beyond Pinhão; this is the most important stream in Tras os Montes. Unfortunately its banks are rugged and precipitous, rising in places over 1,500 feet; it has moreover a tortuous and narrow course, quite unsuited to the construction of a railway, but by keeping to the upper ground on the right bank, as far as Abreiro, it was found that the valley there opens, and offers every facility for laying out an easy line, the curves required are never less than 656 feet radius, and the steepest gradients are 1 in 84, with exceptional instances of 1 in 70 and 1 in 66, in the 33 miles to Mirandella. At this latter point it became advisable to leave the Tua and make for Bragança, an important town at the extreme end of the province, so the watershed which separates the Tua from the Sabor was selected, and a most fertile district can be traversed without any serious difficulty, but the gradients have in places to be increased to 1 in 40.

Pocinho to the frontier of Zamora.—This line is laid out on the high ground between the rivers Sabor and Douro, which here take a northern course. It rises 1,500 feet in the first 58 miles. One of the sections has four tunnels, two viaducts, and some heavy cuttings, but the remainder are comparatively easy, the ruling gradient is 1 in 42, and the curves are chiefly of 492 feet and 656 feet radius. The line, besides serving a populous country, will pass through the mineral district of Moncorvo, rich in iron ore, and which would of itself warrant the construction of a railway.

Mirandella to Vinhaes is a branch from the line first described, following the course of the river Tua. The ground to be traversed involves serious difficulties in the construction, the earthworks are described as considerable, and eleven tunnels are required, having a total length of 1,980 yards, besides extensive viaducts. The

Author remarks that a good roadway from Vinhaes to Bragança would lessen the importance of this line, and its construction might thus be postponed.

Marco de Canavezes to Chaves.—This route was chosen along the left bank of the river Tamga, as it proved on examination to be the most suitable course. Although a portion of the district is thinly populated Chaves is an important centre of traffic, and the celebrated mineral springs of Vidago will be rendered accessible by rail.

Villa Nova de Famalicão to Caves starts from the Minho railway and joins the previous line at Caves; it opens out a populous, commercial, and well-cultivated area. Besides accommodating places of importance, such as Guimaraes, it will pass near to the mineral baths of Vizella, so greatly esteemed in the north of Portugal, and visited by many thousands annually.

The Author examined various other routes, which he considers should be utilized hereafter, so as to complete the network of narrow-gauge lines throughout the two provinces. The lengths and estimated cost of those more particularly described are given in the following Table :—

Name of Railway.	Length.	Cost.
	Miles.	£.
Tua to Mirandella and Bragança	75	605,100
Pocinho to the Zamora frontier	74	502,500
Mirandella to Vinhaes	29	313,300
Marco de Canavezes to Chaves	65	722,200
Famalicão to Caves, and Regoa to Seixo	106	922,200
Total	349	3,065,300

Certain portions of these lines require to be further surveyed and improved, by which it is considered their total cost may be reduced to about £2,700,000.

G. Kn.

The First Rack-railway in Prussia. By O. Sarrazin.

(Wochenblatt für Architekten und Ingenieure, 1880, p. 419.)

The rich lead and silver mines of the Friedrichshagen Consolidated Company of Oberlahnstein are situated between Ems and Lahnstein, about 1½ mile from the banks of the Lahn. The company employs nearly one thousand workpeople, male and female, and in 1878 raised 14,000 tons of ore, which had to be transported at the rate of 46 tons a day down the valley to the river, there to be conveyed in barges to its destination. The system of land carriage being no longer equal to the require-

ments of the mine, it was determined to make a private railway on the Riggenbach system. The line, which was opened on the 8th of November, 1880, is partly ordinary and partly rack railway. The difference of level between the two termini is 384 feet, which had to be surmounted in a length of 8,200 feet, thus giving 1 in 21·4 as the mean gradient. The steepest part worked by adhesion is 1 in 20·5, and by the rack rail 1 in 10. The racked portion is altogether 1,968 feet long, divided into three inclines of respectively 262, 1,165, and 541 feet each. The width of the gauge is 1 mètre (3·28 feet). The curves on the racked portions are everywhere of a radius of 475 feet. At both ends, and at the middle of the line for the dressing floors, are sidings reached by switches of the ordinary construction, and a turntable affords access to the tracks laid in the works below. The teeth of the rack are 3·9 inches from centre to centre; it weighs 90 lbs. per yard, and cost about 22*s.* per yard at the works. The rails, 3¾ inches high, weigh 50 lbs. per yard, and cost £8 10*s.* per (metric) ton. In spite of the generally economical nature of the line, it was impossible to avoid some heavy works in cuttings and banks, the excavation in rock amounting to more than 15,000 cubic yards. It was also necessary to cross the line of the Nassau railway, the many streams in the valley, and the road leading to the Friedrichshagen works. Some of the bridges are of iron, but the greater part are of masonry. The working stock is at present limited to one locomotive and eighteen wagons. The engine, constructed in the works of the Swiss central railway at Olten, weighs 10 tons, or with fuel and water, 11·8 tons, and cost £1,120.

Its load is 10 tons up to the mine, and 18 tons down to the valley. The wagons weigh 0·9 ton each, and carry 2·5 tons. They are provided with brakes, and cost £32 10*s.* each. The greatest speed is six miles an hour. The line was begun in April 1880, and was only seven months in making. It cost, including working stock, 150,000 marks (£7,500) or 60,000 marks per kilomètre (£4,800 per mile), which compares favourably with similar lines in Switzerland, costing from 140,000 to 97,000 marks per kilomètre. This makes the tenth railway in Europe on the Riggenbach system, the others being at Arth-Rigi,[1] Vitznau-Rigi, Rohrschach-Heiden, and quarry lines at Ostermundingen and Laufen,[2] and the Rüti line in Switzerland; Kahlenberg,[3] and Schabenberg[4] in Austria-Hungaria; and the Wasseralfingen[5] line in Würtemburg.

F. G. D.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxx., p. 103; vol. xli., 276.
[2] *Ibid.*, vol. lviii., 346. [3] *Ibid.*, vol. xli., 276. [4] *Ibid.*, vol. lviii., 336.
[5] *Ibid.*, vol. liii., 336.

The Behaviour of Railway Carriages in passing Curves.

By F. HOFFMANN.

(Mittheilungen des sächsischen Ingenieur- und Architekten-Vereins, 1879, p. 100.)

The Author draws attention first to the case of a simple wagon with rigid wheel-base, and on each of whose axles two wheels with coned tires are immovably fixed. He gives the most general form of equation between work and resistance on a curve, and thence derives the form it takes in practical cases, viz.,

$$K = Gf\left(\frac{L}{R} + \frac{s}{R} - \frac{1-a}{1+a} - \frac{1-b}{1+b}\right). \quad (1)$$

where K is the resistance, G whole load on one axle, f coefficient of friction, L wheel base, R radius of a curve, s the width of gauge from centre to centre of rails, a ratio of running radius of inner to that of outer wheel on front axle, and b the same ratio for hind axle. The part $Gf\frac{L}{R}$ is due to transverse sliding, the rest to the rotation of one wheel about the other on each axle. This expression shows that the resistance is small for light load, smooth rails, narrow gauge, short wheel-base, large radius of curvature, and values of a and b near the limit $\frac{R}{R+s}$.

Of the equations—

$$K = Gf\frac{L}{R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$K = Gf\left(\frac{L}{R} + \frac{s}{2R}\right) \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$K = Gf\left(\frac{L}{R} + \frac{s}{R}\right) \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$K = Gf\left(\frac{L}{R} + \frac{2s}{R}\right) \quad . \quad . \quad . \quad . \quad . \quad (5)$$

(2) holds for both axles in outer contact, thus $a = b = \frac{R}{R+s}$; (3) for either axle in outer contact, and the other on the middle of the line; (4) for a diagonal position, thus $a = \frac{1}{b} = \frac{R}{R+s}$, or $= \frac{R+s}{R}$, or for the wagon set fairly on the middle of the line, thus $a = b = 1$; (5) for inner contact of both axles, thus $a = b = \frac{R+s}{R}$.

For investigation of actual resistances and wear, the position assumed by the wagon under the conditions that generally hold in practice must be ascertained. Experience proved that the front axle of a wagon with rigid wheel-base always ran in outer contact. Theory shows that it could only be otherwise if the wheel-base were $< \frac{1}{2}$ the gauge. Less was known of the behaviour of the hind axle; to solve the question trials were made on a line with curves of radii down to $8\frac{1}{2}$ chains, with wagons of 16·4 and 8·2 feet wheel-bases, in which an arrangement of mirrors showed the play between flange and rail to occupants of the wagon. It was found that the tendency of the hind axle to run in inner contact was much greater for the long than for the short wheel-base; for the latter indeed it ran in outer contact when the curvature was small. Reasons are then given for assuming the law, that the hind axle of a four-wheeled wagon with rigid wheel-base always takes a radial position if sufficient play be provided on the line. Its accuracy was confirmed by experiments with a model. Hence the distance between outer rail and outer flange of hind axle being the height of a chord equal to twice the wheel-base is

$$\sigma_h = \frac{L^2}{2R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

but if σ the whole play be $< \frac{L^2}{2R}$, then:

$$\sigma_h = \sigma \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

and corresponding to these values of σ_h we have for the sine of the angle of contact of outer front wheel:

$$\sin \beta = \frac{L}{R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

or

$$\sin \beta = \frac{L}{2R} + \frac{\sigma}{L} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

The constraint necessary to alter the position of a wagon turning a curve arises partly through the axle seats, but chiefly from the lateral pressure between the rail and the outer flange of the front axle. For the former the maximum value is $K_1 = G f \frac{s}{R} \times f_1 \frac{d}{2r}$, where f_1 is coefficient of friction between axle and axle-seat, d diameter of an axle-arm, and r radius of a wheel; this is a consequence of the geometrical connection of the axles and wagon. The expression for the lateral pressure is

$$P_a = G \left\{ \frac{f\left(1 + \frac{s}{2L}\right)}{\cos \beta} + \frac{V^2}{gR} - \left(\frac{h}{s} + \sigma \tan \alpha\right) \right\},$$

where V is the velocity, g the acceleration for gravity, h the cant of outer rail, and α the angle of conicity of the tires: here no allowance is made for friction between flange and rail, but if f_2 be the coefficient, and the actual place of contact be considered, we have for lateral pressure, $K_2 = \frac{0{\cdot}9 \sin \beta}{r} P_a \times f_2$. The three members of P_a are due to the force to make the front axle take its altered position, centrifugal force, and the force arising from cant. The total curve resistance is $K\gamma = K + K_1 + K_2$, and for a diagonal position of the wagon with the front axle in outer contact, which is the position occurring in practice,

$$K\gamma = Gf\left(\frac{L+s}{R}\right) + Gf\frac{s}{R} \times f_1 \frac{d}{2r} + \frac{0{\cdot}9 \sin \beta}{r} P_a f_2 \quad (10)$$

where the values may be $f = \frac{1}{5}$, $f_1 = \frac{1}{25}$, $f_2 = \frac{1}{3}$, and the second member may, in most cases, be neglected. K_1 and K_2 have not, to the Author's knowledge, been taken into account hitherto. K arising from horizontal shifting causes wear of the rail tops, and affects the inner rail most; K_1 causes wear of the axle seats and holders only; K_2 resembles the action of a blunt cutter, the flange of the outer front wheel being the cutter, and the inside of outer rail the object cut. For carriages in a train the value of P_a is altered by forces in the couplings, and the Author investigates this effect minutely.

Dealing next with six-wheeled carriages, if to the middle axle no more than the necessary play be given by thinned flanges, cylindrical are better than conical tires; but with the usual spread of gauge at curves no lateral play is required for the middle axle. If there be no spread of gauge, safety requires a lateral play of 0·2 inch only for a wheel-base suited to the curve; but a wheel-base of 19·7 feet would require 0·8 inch on a curve of 8·5 chains radius. Supposing the loads G on the end axles equal, and that on the middle axle a fraction n of each of these; so that, Q being the weight of the carriage, $G = \frac{Q}{n+2}$ and $G_m = \frac{nQ}{n+2}$, the whole resistance is—

for inner contact of middle axle:

$$K''' = \frac{Qf}{R}\left\{\frac{(L+s) + n\left(\frac{L}{2}+s\right)}{n+2}\right\} \quad . \quad (11)$$

for outer contact of middle axle:

$$K''' = \frac{Qf}{R}\left\{\frac{(L+s) + n\frac{L}{2}}{n+2}\right\} \quad . \quad . \quad . \quad (12)$$

Comparison of these equations with (4) shows that a six-wheeled rigid-axled carriage passes curves with less resistance than a four-wheeled one of equal weight and wheel-base, if the middle axle can run in outer contact, but with greater if its play allows only of inner contact. The minimum lateral play required to allow the middle axle run in outer contact is $\frac{L^2}{8R} + \frac{\sigma}{2}$.

The cant of the outer rail, when adapted to neutralise centrifugal force, is obtained from the equation

$$h = s\left(\frac{V^2}{gR} - \sigma \tan \alpha\right) \quad . \quad . \quad . \quad . \quad (13)$$

After treating generally of the question of spread of gauge, the Author sums up with the conclusions:—1. Four-wheeled wagons with rigid wheel-base pass curves with greater safety when there is no spread of gauge, and the flanges are unworn, since the angle of contact is then diminished by half; 2. Such wagons run on curves of the minimum radii for their wheel-bases, and with the usual spread of gauge, with the hind axle in inner contact, and with less constraint than if there were no spread of gauge; 3. With the usual spread of gauge the curve resistance is less for worn-out than for unworn tires.

Security is dependent on the relations existing for the outer front wheel, and is greater the greater the vertical, the less the lateral pressure, the smaller the angle of contact, and the more sharply rounded and vertical the places of contact between flange and rail.

The curve resistance and wear are less, the less the vertical and lateral pressure, the less the angle of contact, and the nearer the places of contact between flange and rail lie to the crown of the rail, and for the least possible rounding of these places.

A table is given with corresponding values of R, L, V, h, σ, β, lateral pressure, and total curve resistance of four-wheeled wagons and locomotives with rigid wheel-base.

Arrangements for facilitating the use of longer carriages on curves are next considered. When a carriage constructed on the American bogie system runs on a curve, each car will clearly follow a tangential direction till it runs against the outer rail, and and then assume the position natural to a rigid-axled wagon. Owing to the smallness of the distance $\frac{l^2}{2R}$ (l being the bogie wheel-base) of the hind axle of each car from the outer rail equation (2) holds approximately for each; hence the whole curve resistance to produce the altered direction of the carriage is $2\,G_1 f \frac{1}{R}$, G_1 being the load on a single car axle. If again for a locomotive a bogie be used in front, with a rigid axle behind, the resistance, though less than for a rigid four-wheeler, is large com-

pared with the value just given. Since bogies with more than one axle have the disadvantage of complication, and for locomotives of reducing the load on the front outer wheel, numerous systems of flexible single axles have been devised. Of these the Adams guided axle, and the Bissel front axle for locomotives, have been laid aside on account of their dependency for steady motion on the presence of two rigid axles of long wheel-base.

Mr. John Clark devised a three-axled wagon, used on Mount Cenis, in which the axle-boxes were so connected by mechanism that the yielding of the middle axle through the height of a chord equal to the wheel-base caused the end axles to run radially. If λ denote the yielding of the middle axle, ϕ the angular turning of the end axles, since $\lambda = \frac{L^2}{8R}$, and $\sin \phi = \frac{L}{2R}$, the condition to be fulfilled by the mechanism is $\sin \phi = 4\frac{\lambda}{L}$, which shows that it will suit curves of any radius. With this, and the Cleminson system on the same principle, the curve resistance and lateral pressure can be almost totally removed.

For a locomotive with the Nowotny front axle, which differs from the Bissel axle in having the pivot above the middle of the line joining the wheel centres, instead of being somewhat behind this position, experience has shown that the duration of the front tires, and proportionally of the rails, is four times > for a rigid axled locomotive of the same wheel-base.

In the search for a simple system of flexible axles for wagons, the central pivot being laid aside, an arrangement allowing the journals with their covers to slide in the long direction of the wagon against single or double incline seats in the boxes, with a central holder to neutralise shocks, was adopted with success. A simpler method lay in providing suitable play between axle-box and holder, with the necessary turning power between bearing spring and axle-box. Several forms of couplings for flexible axles are shown by drawings.

A. Br.

On the Construction, Performance, and Working of Light Railway Locomotives. By Hr. von Borries, of Hanover.

(Glaser's Annalen, vol. vii., 1880, p. 43.)

This is an essay towards settling the conditions, leading dimensions, &c., of engines for working "secondary" or light railways, based on the general principles laid down in Germany for the construction of locomotives, and the building and working of light railways. Three different gauges are considered throughout, viz., standard gauge (4 feet 8½ inches), mètre gauge (3 feet 3⅜ inches), and ¾ mètre gauge (2 feet 5½ inches).

Load per Axle.—This is the first element to be fixed in all rolling stock. In light railways the rails are proportioned to the heaviest goods wagon which will run on the line, and the weight per axle of the locomotive must conform to this. With standard gauge, where main line wagons may come over the line, the load per axle should be taken at 9 tons; with mètre gauge at 7½ tons (taking 10 tons as load of wagon, and 5 tons as its weight); with ¾ mètre gauge at 3¾ tons (5 tons for load, 2½ tons for weight of wagon). These figures agree with the rules of the German Railway Union, except that they give 5 tons for ¾ mètre gauge, which seems excessive.

General principles.—The leading principles should be simplicity of construction and facility of maintenance. The blast-pipe should be retained, as the most economical and automatic method of forcing the fire, and the condensation of the steam, sometimes insisted on in populous districts, should be avoided as much as possible, on account of the expense. The engines should be tank engines, 4-coupled or 6-coupled, according to the work to be done. They should be no heavier than is required to produce the requisite tractive force by adhesion, and the speed on steep gradients should be lowered so that a boiler suited to this weight may generate the needful amount of steam. For very steep gradients, the requisite weight may be obtained by using special engines, designed to carry luggage or passengers as part of their load.[1] A 4-coupled engine is to be preferred, unless the traffic is heavy, or the conditions unfavourable. The train officials should be reduced in number as far as possible, since each may be taken to absorb in wages from 6 to 15 per cent. of the working cost. On light railways the full services of both driver and fireman are not needed for the engine, and therefore the latter may also act as a brakesman, working not only the engine brakes, but also those in the front van, which should be placed in communication with the engine. The guard would also act as a brakesman for his own van, which should always be at the rear of the train, and no other brakesman would be necessary. Continuous brakes are not worth their expense, especially looking to the probability of goods wagons being mixed in the train; but, as a provision for emergency, such goods wagons may be fitted with lever brakes on the Exter system, which may be worked from the engine by means of a cord. The engines should have a gangway at each side, and provision at each end for stepping on to an adjoining vehicle.

Provisions against fire, and against the frightening of horses.—The danger of fire must be completely obviated by proper spark-catchers or extinguishers, and by closing in the ash-pan, so that no cinders can escape. Horses are found to be frightened mainly by the sight of a carriage apparently running of itself, by violent puffs of smoke or steam (not the mere escape of steam at the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lxi., p. 369: "Van Locomotive."

chimney), and by rapidly moving gear. These causes can be removed to a great extent, if not entirely, by boxing up the gear, by placing an air vessel in the exhaust pipe, and by turning the escape from the cylinders and safety-valves into the condenser, and that from the injector into the tank.

Leading dimensions.—The engines are taken to weigh about 90 lbs. per square foot of heating surface; it being assumed that they are built on the Krauss system, and that the grate surface and tank capacity will be varied according to the gauge. The useful steam generated is taken at 5 lbs. per square foot of heating surface per hour, with a pressure of 150 lbs. The latest cut-off, on the steepest gradient, should not exceed 0·4 of the stroke, which gives mean pressure = 97 lbs., and work done per pound of steam = 102,000 foot-lbs. The adhesion coefficient, with sanded rails, may be taken at 0·15; whence, assuming that the engine may lose 11 per cent. of its full weight, through consumption of fuel and water, the tractive force may be taken as 0·133 of the full weight. The wheel diameter for standard gauge may be taken as 3 feet 3 inches, the same as for the carriages, which, at 18 miles an hour, the maximum speed, gives 2·8 revolutions per second. For the narrower gauges the speed should not exceed 12 to 15 miles an hour, and the diameter of the wheels may be from 2 feet to 2 feet 8 inches. The length of stroke should be about half the wheel diameter. The cylinder diameter may be calculated (for metric measures) from the following equation: $d^2 = 0{\cdot}011 \times \frac{\text{Tractive force}}{3{\cdot}4}$, where 0·011 is Koch's value for the coefficient of machine friction in locomotives. The grate surface should be as large as possible, say $\frac{1}{50}$ heating surface for standard gauge, $\frac{1}{60}$ for mètre gauge. The tank may hold 3½ cubic feet, and the bunkers 1·1 cubic foot, per ton of engine weight. The above and other leading particulars are combined in the following Table:—

TABLE I.—LEADING DIMENSIONS.

Gauge	Standard.		Mètre.		¾ Mètre.	
Number of wheels	4	6	4	6	4	6
Full weight . . . . . tons	18	27	15	22½	7½	11·3
Heating surface . . sq. feet	430	646	355	538	177	269
Grate „ . . „	7·6	12·9	6·0	9·0	3·0	4·5
Pressure . . . lbs. per sq. in.	150	150	150	150	150	150
Diameter of wheels . . inches	39	39	31·5	31·5	24	24
„ „ cylinder . . „	11·0	13·4	9·9	12·2	7·1	8·7
Stroke „ „ . . „	19·5	19·5	15·7	15·7	12·0	12·0
Capacity of tank . . c. yds.	2·9	4·2	2·15	3·25	0·98	1·45
„ „ bunkers . „	0·7	1·0	0·6	0·9	0·3	0·45
Wheel-base . . . . . feet	8·2	9·8	6·6	8·2	5·25	6·6
Tractive force (without friction). . . . . tons	2·4	3·6	2·0	3·0	1·0	1·5

Performance of the engines on various gradients.—The various figures assumed above give an effective power for the engine of about 6·3 HP. per ton weight. The tractive force per ton weight, including friction, will be about 321 lbs., whence it is calculated that the speed required to develop the maximum tractive force is 7 miles an hour; and this should therefore be taken as the speed on the steepest gradient of the line. On this assumption the maximum haulage load on various gradients, exclusive of the engine, is given by the following Table:—

TABLE II.

Gauge.	Weight of Engine.	Tractive Force.	Maximum Weight (Tons) of Train on Gradient of									
			1 in 200	1 in 150	1 in 100	1 in 80.	1 in 60.	1 in 50.	1 in 40.	1 in 30.	1 in 25.	1 in 20.
	Tons.	Tons.										
Standard	18·0	2·4	320	255	180	146	110	91	71	50	39	28
	27·0	3·6	475	385	270	220	166	136	116	75	59	42
Mètre	15·0	2·0	265	213	150	122	92	75	59	42	33	24
	22·5	3·0	400	320	225	183	128	114	89	63	49	35
⅔ Mètre	7·5	1·0	132	107	75	61	46	38	30	21	16	12
	11·3	1·5	200	160	113	92	70	57	45	31	25	18

Working.—The cost of fuel and repairs may be greatly diminished on light railways, by keeping the speeds on gradients below the steepest at a proper limit; the principle being that the generation of steam should never be faster than it is on the steepest gradient. If this gradient is greater than 1 in 100, the evaporation, with lighter gradients and higher speed, will remain about the same. If it is less than 1 in 100, the evaporation diminishes rapidly on lighter gradients, and the speed must therefore be regulated by some positive limit, which in Germany is 18 miles an hour.

The gross consumption of water per hour may be taken at 6·5 lbs. per square foot of heating surface, or 0·075 of the weight of the engine. The total weight of water in the tank may be taken at 0·1 of the engine weight; and, assuming that one quarter of this should be reserved for emergencies, it would follow that the watering stations should be one hour's distance apart. But this assumes that the engine will always be exerting its maximum power, and, taking this and other circumstances into consideration, the watering stations may be placed at about double the above distance. They should be of the simplest character, generally consisting of a well from which water may be drawn by an ejector or pulsometer, worked by the engine. It is only at the engine-sheds that a tank is necessary, and this may be filled by means of the steam left in the engines when they come in. As to the distance between the coaling stations, assuming that each

pound of coal will evaporate 8 lbs. of water, and that the capacity of the bunkers is only one quarter that of the tank, it will follow that this should be double the distance between the watering stations.

W. R. B.

Steam-Traverser. By M. MAYER.

(Annales Industrielles, September 26, 1880, col. 395.)

This traverser, worked by steam, is in use on the Western Railway of France, for marshalling loaded wagons. It consists of a steam car, and a table or wagon-platform attached to the car. The car is 22 feet long, and 21¾ feet wide, carried with springs on four wheels, 28 inches in diameter, on axles about 6 feet apart. Steam is supplied from a tubular boiler, to a double-cylinder inverted engine with reversing gear. By means of two hand-levers conveniently placed, the car can be traversed; and wagons can be drawn on to the table by a rope wound on a drum, and guided over pulleys at the four corners. The car is held at rest by means of a detent let down into a slot in the upper head of one of the rails. The table or platform is mounted on eighteen 12-inch wheels. The body of the steam-car is built of sheet-iron and angle-iron. There are two doors, one at each end of the body, so that the stoker and the engineer may not hinder each other in passing in and out.

D. K. C.

On the Compounding of Locomotives. By Hr. VON BORRIES.

(Zeitschrift des Vereines deutscher Ingenieure, 1880, p. 447.)

This is mainly a description of a compound locomotive designed by the Author, as an improvement on the well-known and successful system of M. Mallet.[1] One difficulty with all compound engines, but especially locomotives, is to provide a rapid and simple means of starting the engine, if the crank of the small cylinder happens to be left exactly on the dead centre. M. Mallet gets over this by means of a special starting valve, which enables steam to be admitted direct to the large as well as the small cylinder if required, the engine then working for the time like an ordinary locomotive. By means of an additional automatic reducing valve, the steam under these circumstances can be made to have a less pressure in the large than in the small cylinder, and thus the work done in the two cylinders can be equalised, which is in some cases an advantage. Again, it is usually desirable to cut off the steam in the large cylinder at a

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. li., p. 214; vol. lix., p. 349.

different point from that in the small cylinder, chiefly to avoid the drop in pressure which otherwise occurs between the two cylinders. If the link motions of the two cylinders are actuated by the same reversing handle as usual, this cannot be effected. M. Mallet therefore provides separate weigh-shafts and levers for the two link motions: the lever of the small cylinder he connects direct to the nut of a reversing screw, while that of the large cylinder he connects to a hand lever, which can be shifted to different positions on a toothed sector, moving with the nut on the reversing screw. By setting the hand lever to different notches of the sector, the points of cut-off in the two cylinders can be varied at will.

The Author admits the skill of these arrangements, but considers them wanting in simplicity, and especially that they impose upon the driver a method of manipulation to which he is unaccustomed; while the working of the engine direct, when upon steep gradients, is very wasteful of steam at the time when it is most needed. He therefore lays down the following conditions:—(1) The engine must always work compound; (2) The starting and valve gear must be simple to construct and manipulate; (3) For any grade of expansion in the small cylinder, the best corresponding grade in the large cylinder must be given automatically, without the intervention of the driver.

The starting gear, in the Author's design, is a modification of the ordinary regulator. There are two slides, one on the back of the other, the upper being moved as usual by the handle, and the lower being moved by overhanging flanges on the upper. A small opening, through one end of the valve chest, communicates with a pipe which leads to the receiver. The first motion of the upper valve, in starting, admits the boiler steam to this opening, and therefore to the large cylinder, but at a reduced pressure, the amount of which can be varied by varying the size of the opening; at the same time steam, at nearly full pressure, passes through another and larger opening to the small cylinder. As soon as the engine is thus started, the driver, following his custom, pulls the slide over a little further, and by that means closes the opening to the large cylinder, while giving yet fuller admission to the small cylinder. With regard to the reversing gear, the Author shows that, if the ratio of the areas of the two pistons is as 1 : 2·25, or 1 : 2·5, the best cut-off will always be at the same point in both cylinders, and therefore only one reversing motion is needed. For large engines, however, this ratio is too great to be manageable, and gives too unequal a distribution of work; a ratio of 1 : 1·9 is there found to be the best, and this necessitates a variation in the two cut-offs. For this purpose separate weigh-shafts are provided as by M. Mallet: that of the small cylinder is worked direct by the ordinary reversing lever, while that of the large cylinder is connected to another lever, turning on the same centre as the reversing lever, and capable of being set to move with it, but at a different angle. The result is that, on setting the ordinary lever to give any required cut-off in the small cylinder, the proper corresponding

cut-off is approximately given by means of the second lever in the large cylinder.

It will be seen that these arrangements fulfil the conditions laid down above. A compound engine on this system, as compared with an ordinary locomotive, has not only the common advantages of the compound engine (especially the avoidance of great changes of temperature within the cylinder), but has others peculiar to itself. A locomotive is comparatively seldom under its maximum load, and therefore should generally be worked with a high grade of expansion. But where this is given in a single cylinder, and by the ordinary slides, there is so much wire-drawing at the beginning, and compression at the end of the stroke, that economy of working is sacrificed. By dividing the expansion between two cylinders, and thus having a far lower grade in each, this evil is done away with. Again, the longer maintenance of the full pressure within each cylinder places the useful work in a much more favourable relation to the engine friction—a quantity which, especially with 6-coupled and 8-coupled locomotives, is considerable. The net pressure on the slides, and therefore their friction and wear, is also diminished by one-half; while, since the total pressure in the large cylinder is never materially greater than in the small, the dimensions of the piston-rod and other working parts may be the same in both.

As the result of his system, the Author estimates that a saving in fuel of at least 15 to 20 per cent. may be reckoned upon. He is now building four sister engines, two on the ordinary plan, and two on the new compound system, and hopes soon to publish the results of comparative experiments between them.

W. R. B.

Recent Legislation on Steam Boilers in France.

(Société Scientifique Industrielle de Marseille, 1880.)

By a recent decree of the President of the French Republic, dated April 30, 1880, the Government regulations for stationary, portable, and locomotive steam boilers, passed in 1865, have been modified and adapted to more modern experience. There is no change in the essential conditions of the proving of new boilers, but boilers are now to be proved at least once in ten years, as well as after every important repair. The most important innovation in the new law is its extension to steam-chambers or reservoirs having a volume greater than 100 litres, or 3½ cubic feet: such as drying cylinders and heaters with double bottoms, also fireless locomotives.

The proof, which is made under the direction of an engineer of mines, consists of hydraulic pressure, equal to twice the effective working pressure; but the excess pressure is never to be less than half an atmosphere, nor more than 6 atmospheres. The limit of

working pressure, expressed in atmospheres (kilogrammes par centimètre carré) on a stamp, dated, affixed to the boiler. Each boiler is to be fitted with two safety-valves, to blow off at such a pressure that the authorised limit of pressure may never be exceeded. A pressure-gauge is to be attached to the boiler. A check-valve is to be attached to the feed-pipe. A shut-off valve or cock is to be fixed on the steam-pipe, as near as may be practicable to the boiler. Fire-heated plates are to be covered by at least $2\frac{1}{2}$ inches of water, excepting in the case of superheaters distinct from the boiler, or of chimneys traversing the steam-space. Two gauges for water-level are to be provided, one of them being a glass gauge.

Steam boilers are to be registered at the prefecture. They are divided into three categories based on the product of the total capacity of the boiler (including feed-heaters), in cubic mètres, by the excess temperature, in centigrade degrees, of ordinary steam at the authorised pressure above 100° Centigrade. For two or more boilers in communication, the total capacity is taken as the factor. For the first category, the product exceeds 200; for the second, it does not exceed 200, and is greater than 50; for the third, it does not exceed 50.

Next follow the conditions for boilers which are placed near dwelling-houses. For boilers in mines, special provisions are made by the local prefect on the report of the Engineer of Mines.

D. K. C.

Non-condensing Compound semi-portable Engine.

By MM. CHALIGNY and GUYOT-SIONNEST.

(Annales Industrielles, August 29, 1880, col. 273.)

Two semi-portable engines, with compound cylinders, have been constructed for the French naval service. On a boiler of the locomotive type, the engine is placed horizontally as in ordinary semi-portable engines. The cylinders are respectively 11 inches and 19 inches in diameter, with a stroke of $17\frac{3}{4}$ inches. They are connected to cranks at right angles, and have an intermediate receiver for the steam from the first cylinder, from which it is delivered to the second cylinder. The steam is exhausted from the second cylinder into the atmosphere by the chimney. The capacities of the cylinders are as 1 to 3; the capacity of the receiver is $1\frac{1}{3}$ time that of the first cylinder. The steam is cut off in the first cylinder at from $\frac{6}{10}$ths to $\frac{8}{10}$ths of the stroke, and in the second cylinder at $\frac{6}{10}$ths: expanding the steam by from $3\frac{3}{4}$ to 5 times. The engine makes ninety turns per minute. The power at the brake, for steam of a pressure of 75 lbs. per square inch, expanded 5 times, is 42 HP.; expanded $3\frac{3}{4}$ times, the power is 55 HP.

From official trials it was found that, for an indicator power of 53½ HP., the power at the brake was 46 HP., or 86 per cent. of the indicator power. The water was consumed at the rate of 29 lbs. per brake HP., or 25 lbs. per indicated HP.

D. K. C.

New Motor.

(Mittheilungen aus dem Gebiete des Seewesens, vol. viii., p. 610.)

This motor is made by Julius Hock and Co., of Vienna, but differs considerably from the well-known hot-air engines hitherto constructed by them.

The action is similar to that of a steam-engine, with the exception that the steam is produced without a boiler. A pump compresses air into a hermetically-closed stove, where it supports combustion and mixes with the resulting products; on its passage from the stove the mixture meets a fine stream of water, by which the gases are cooled and the water turned into steam, the steam and gas then pass to the motor cylinder, which may be that of an ordinary steam-engine, the cylinder being lubricated by water.

These machines are simple and economical, the consumption of fuel being about 2¼ lbs. per HP. per hour, and contrary to hot-air engines, the makers consider them available for large as well as small powers.

W. P.

Note on Hall's Pulsometer. By M. de Maupeou.

(Journal de Mathématiques, vol. vi., p. 267.)

After giving a detailed account of the construction of the pulsometer, the Author proceeds to notice some competitive trials recently held at Cherbourg arsenal. A pulsometer of 30 tons, raising about 6,000 gallons per hour (which appears to be a little larger than the No. 4 size in the English make), was tried against an American injector constructed by M. Peteau. Pressures of 25, 32, 56, and 71 lbs. per square inch were employed, these corresponding to different types of boilers, and the water was raised in succession to 3, 4, 5, 6, 7, 8 mètres (10 to 26 feet). The supply of water was taken from a tank kept at a constant level. The delivery was recorded and also the difference of temperature between the water on entering and leaving the pump, which latter was found to be almost invariably 3·6° Fahrenheit. The trial was conducted by M. Bigot, manager of the boiler works, and great care was taken, by constantly regulating the supply of steam and the taps on the vessels, to obtain the best possible result.

The first experiments were to ascertain the effect, upon the working of the pump, of the dirty water from the bilge of a steam-

ship; to this end, coal dust which had been passed through a 0·2-inch mesh sieve was added to the water in the tank with the following results:—

Duration of Experiment.	Depth in Feet.		Coal Dust Raised in lbs.	Water Raised in lbs.	Total.
	Suction.	Forcing.			
One hour	3·3	23·0	2,640	57,200	59,840
„	..	26·25	3,300	56,760	60,060

Thus, though the amount of coal raised was considerable, the apparatus worked well.

The second series of experiments was made to obtain the fuel used, it being assumed that each kilogramme of coal furnishes 5,060 calories (*i.e.* 9,090 thermal units per lb. of coal); this quantity, corresponding to a little less than 8 litres, evaporated per kilogramme of fuel, with the feed water at 59° Fahrenheit. It was found that (1) For a given height of delivery, increase of pressure augmented a little the quantity raised. (2) The total height to which water can be raised is proportional to the pressure of steam. The other results are shown in the Table.

Total Elevation. H.	Number of Pulsations per Minute. N.	Delivery in Gallons.		Expenditure of Coal per HP measured by Water raised. P.	Product P × H.
		Per Hour. D.	Per Pulsation. $\frac{D}{N \times 60}$.		
3 mètres, or 9·9 feet	103·7	7382·1	1·1748	79·86	790·6
4 „ 13·1 „	97·0	7166·5	1·0298	59·62	787·1
5 „ 16·4 „	92·5	6803·5	1·1858	47·74	787·8
6 „ 19·7 „	86·5	6429·5	1·2364	39·60	784·3
7 „ 23·0 „	83·0	6325·0	1·2694	33·88	782·9
8 „ 26·25 „	82·2	6297·8	1·2738	29·70	789·9

From these figures the important result is deduced, that (the increase in the temperature of the water used being nearly constant) "the expenditure of steam and coal is sensibly proportional to the delivery, and independent of the height of elevation." It follows that the efficiency of the apparatus increases with this height. Further it is seen that the number of pulsations increases as the lift is diminished, and that the delivery increases nearly in the same proportion.

Figures are not given for the comparative performance of the injector, but it is stated that the expenditure of coal, for a given amount of work, also decreased nearly in the inverse ratio to the height of elevation, but the delivery increased rapidly with increase

of pressure and with decrease of lift, which constituted a notable point of difference to the action of the pulsometer.

The next Table deals with cost, as follows :—

	Delivery in Gallons per Hour.	Weight in lbs.	Price in Francs.			Observation.
			Total.	Per lb. Weight.	Per 1,000 Gallons Delivery.	
Thirion pump . .	6,000	1,122·0	3,000	2·7	500·0	120 revolutions.
Injector	4,000	35·2	135	3·8	33·75	
Pulsometer . . .	6,000	242·0	1,125	5·0	187·5	

The price of the pulsometer per lb. is therefore very high, especially as its construction is so simple, but this is no doubt due to its novelty. The comparative amount of work done for a given first cost is, however, three times as great as that by the Thirion pump and motor.

The last Table gives the results of a comparison of the expenditure of fuel for various kinds of pumps, both for supplying towns and for bilge pumping, taken from various sources; the results for the centrifugal and Behrens' pump being extracted from the "Mémorial du Génie Maritime" for 1874 and 1877 :—

Nature of Apparatus.		Expenditure of Coal per HP. per hour.
		lbs.
Apparatus for distributing water	Pumps of Ivry, by M. Cavé	6·6
	„ Niort, by M. Cordier	6·6
	„ Angers, by M. Farcot	2·86
	„ Nantes, by M. Windsor	2·64
High-pressure pumps	Established under favourable conditions (calculated)	8·8
	Centrifugal pump at Suffren for raising water 25 feet	15·0
	Behrens' pump fixed in steam launches: Tried at Brest by M. Risbec	15·0
	„ Toulon by M. Choron	29·92
Small-power pumps, tested at Brest by M. Huet	Regulating apparatus	28·6
	Behrens' system	70·0
Pulsometer raising to a height of	13·1 feet	59·4
	19·7 „	39·6
	26·25 „	29·7
Injector raising to a height of	13·1 „	418·0
	19·7 „	277·2
	26·25 „	211·2

The engines of steam launches were supposed to use 6·6 lbs. of coal per hour per HP., this being the average result of experiments by M. Mangin.

The conclusions drawn are, that the pulsometer is simple in action, efficient and durable, very suitable as a bilge pump; but, though more economical in fuel than injectors, cannot in this respect compare with ordinary pumps for application to regular work, such as the distribution of water to towns, unless the water has to be raised in temperature at the same time that it is pumped.

H. S. H. S.

Robelet's Friction-Hammer.

(Annales Industrielles, 26 Sept., 1880, col. 268.)

Robelet's friction-hammer resembles, in its general arrangement, an ordinary steam-hammer; but the motive power is supplied from shafting, by which an intermediate shaft, forming part of the hammer, is driven. The hammer is lifted by means of an ordinary band, which is passed over a flat grooved pulley at the upper part of the machine. The other end of the band hangs down with a handle, within reach of the attendant. When the hammer is to be raised, the band is pulled down over the pulley so that, by the adhesion of the band to the pulley, it is drawn over, and the hammer is lifted by the revolving pulley. The speed of ascent can be regulated by the degree of force exerted at the handle; and that the hammer may fall freely, unhindered by counter friction of the band resting with its own weight on the pulley, the band is slightly raised, so as to be removed out of contact with the pulley, by a circular self-acting spring, which occupies a groove sunk into the rim of the pulley, and expands when the band is released.

The power of the intermediate, or driving shaft, is communicated to the band-pulley by means of friction wheels. To bring these into contact, and so to start the band-pulley, the axle of the pulley is slightly eccentric, so that, when it is turned partly round by means of a hand-wheel and lever, it lowers the pulley into frictional contact.

The force of the fall of the hammer is augmented by the reaction of a pair of helical springs placed above the hammer, which, when it rises, strikes the springs, and rebounds downwards in proportion to the extent to which the springs are momentarily compressed.

The hammer weighs 3½ tons, and its cost is £120. The tup weighs 440 lbs., and the power required is 1 HP.

D. K. C.

Balance-Dynamometer.

(Annales Industrielles, October 17, 1880, col. 496.)

The balance-dynamometer, the invention of M. Em-Denis Farcot, was designed to show the driving power, the resistance and the efficiency of machines driven by bands, at any instant, and for

any speed. The driving power is communicated by a band to the dynamometer, by an upper shaft, from which the power is conveyed by another band to a second and lower shaft, whence it is transmitted by a third band over a pulley on the same shaft to the machine to be tested. The second, or intermediate band is passed over two equal-weighted pulleys on swing frames, one to the right and the other to the left of the second shaft. When the apparatus is connected to the machine, the tension in the second band on the pulling side is measured by a third weight adjusted to restore equilibrium. The product of this amount by the circumferential velocity of the driven pulley on the second shaft represents the work done by the machine. A counter is attached to the apparatus, to record the speed.

D. K. C.

Improvements in Dynamometric Brakes.

By MM. CARPENTIER and MARCEL DEPREZ.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 1880, p. 445.)

It is well known to those who have made experiments with the Prony brake that it is impossible to eliminate the serious oscillations which result from the variations of the frictional element. Some advantage can be realised by placing the arm of the lever below the revolving axle, and further by replacing the weight by a graduated spring, so that the lever exerts more force as its angle of displacement increases. M. Carpentier's arrangement consists of two grooved pulleys, one fast and the other loose, fixed on the axle which furnishes the power to be measured. Two cords, to which weights are suspended, are attached to points on the loose pulley at about 120° apart, the one carrying the larger weight (P) lying freely in its own groove, and that carrying the smaller one (p), lying in the groove of the fast pulley, the point of attachment being for that purpose prolonged and bent over in order to be in its plane. If the axle is turned in the direction in which p acts, the difference of tension at the extremities of the arc touched by its cord increases rapidly with this arc, and equilibrium is established when the tension of the cord at its point of attachment equals P. The friction then exerted by the cord on the moving pulley is equal to $P - p$, and the work developed is given by the expression,

$$(P - p) \times \frac{n}{60} \times 2\pi R,$$

where n is the number of revolutions per minute, and R the radius at which the friction acts. The relation between the weights and the friction is given by the equation $P = p\,e^{fa}$, where f is the coefficient of friction, and a the arc embraced by the cord. If then

f is variable, the angle a varies, so that fa is constant. These oscillations are very slow, and in no way similar to those of the Prony brake. This arrangement is especially suitable for low powers up to 2 HP., and from the equation given above could be applied to the determination of the values of lubricating oils, and in a calorimeter for measuring the mechanical equivalent of heat.

M. Deprez's improvement consists in replacing the bolts and thumb-screws of the Prony brake by leverage, applied automatically by a weight. The two jaws of the brake are hinged on a loose pulley running by the side of the fast one on which they press; two levers are connected to these jaws, and by means of links at their ends, the position of which is unimportant, are connected to another lever, which returns medially between them, and sensibly parallel, and to which a weight is attached so as to hang in the line of the axis of motion; this weight has no place in the calculations, but is merely to act on the jaws. The weight which counterbalances the friction is attached to the periphery of the loose pulley by a steel band, so that its acting distance remains constant for any displacement of that pulley; not so the system of levers, the action of which varies as the sine of their angle of inclination to the vertical. The brake is therefore approximately adjusted so that the levers are inclined at an angle of 30° to the horizon. If the friction increases the angle increases, and the pressure on the jaws diminishes, and *vice versâ*, the apparatus thus regulating itself. It is extremely sensitive, and its simplicity allows of its general adaptation. The Paper is illustrated by detail drawings of both brakes.

F. J.

[NOTE.—The dynamometer here described as invented by M. Carpentier affords an instance of what may be believed to be quite independent inventions of the same thing nearly simultaneously by different persons. A friction ergometer or dynamometer in all its essential arrangements identical with this one was invented some years ago by Professor James Thomson, and has since, from year to year, been shown publicly to his classes of Civil Engineering in the University of Glasgow; it has also been exhibited to different persons for several years past, without any secrecy. A full notice of the instrument will be found in *Engineering*, Oct. 29, 1880, p. 379.—SEC. INST. C.E.]

The Calculation of Stepped Speed Cones. By J. BARTL.

(Civilingenieur, 1880, col. 3–12.)

Suppose two speed cones are arranged for n speeds. Let $r_1 \ldots$ be the radii of the driving pulleys; $R_1 \ldots R_n$ the radii of the driven pulleys; u the constant speed of the driving cone in turns per minute; $u_1 \ldots u_n$ the speeds of the driven cone; a the distance

apart of the shafts; L the length of the belt which is to run on each pair of pulleys; 2ϕ the angle between the tangents to a pair of pulleys, which occupy the place of the free parts of the belt.

Generally there are given u, u_1 and u_n, one radius, as for instance R_1 and the distance a of the shafts. The intermediate speeds must be chosen and the radii determined so as to satisfy the velocity conditions, and also to permit the same belt to be used on all the pairs of pulleys. Let, for simplicity, $\frac{u}{u_1} = \psi_1$, $\frac{u}{u_2} = \psi_2$. Then $\psi_1 = \frac{R_1}{r_1}$, $\psi_2 = \frac{R_2}{r_2}$, are the conditions which ensure the proper velocity ratios.

The well-known equation for an open belt is—

$$L = \pi(R+r) + 2\phi(R-r) + 2a\sqrt{1-\left(\frac{R-r}{a}\right)^2} \quad (1)$$

which is laborious to use.

Now it is convenient that the steps of the cones should be of nearly equal height. Let δ be the mean height of the steps. Then, assuming for the moment δ a constant, we should have—

$$\left.\begin{aligned} r_2 &= r_1 + \delta; & R_2 &= R_1 - \delta; \\ r_n &= r_1 + (n-1)\,\delta; & R_n &= R_1 - (n-1)\,\delta \end{aligned}\right\} \quad . \quad . \quad . \quad (2)$$

Hence—

$$\frac{R_1 - (n-1)\,\delta}{r_1 + (n-1)\,\delta} = \psi_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2a)$$

$$\delta = \frac{R_1 - \psi_n r_1}{(n-1)(\psi_n + 1)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Since ϕ is small, replace it by $\sin\phi = \frac{R-r}{a}$ in equation (1), which then simplifies to—

$$L = (R+r)\,\pi + 2a + \frac{(R-r)^2}{a} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

If the same belt works on each pair of pulleys—

$$\left.\begin{aligned} (R_1+r_1)\,\pi + 2a + \frac{(R_1-r_1)^2}{a} &= (R_2+r_2)\,\pi + 2a + \frac{(R_2-r_2)^2}{a} \\ . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad

R and r, in equation (2). Doing this, and rearranging the terms, the equations (5) become—

$$\left.\begin{aligned} R_2 + r_2 &= (R_1 + r_1) + \frac{4\,\delta}{\pi\,a}[(R_1 - r_1) - \delta] = S_2 \\ &\cdots\cdots\cdots\cdots \\ R_n + r_n &= (R_1 + r_1) + \frac{4\,\delta}{\pi\,a}[(n-1)(R_1 - r_1) - (n-1)^2\delta] = S_n \end{aligned}\right\} \quad (6)$$

From (6) and (2*a*)

$$\left.\begin{aligned} r_2 &= \frac{S_2}{\psi_2 + 1}; \quad r_3 = \frac{S_3}{\psi_3 + 1} \\ R_2 &= S_2 - r_2; \quad R_3 = S_3 - r_3 \end{aligned}\right\} \quad \cdots\cdots\cdots \quad (7)$$

which give directly the required radii in terms of the given quantities. The Author shows by a numerical example that the method gives extremely accurate results.

W. C. U.

On Gas Generators. By Hr. PÜTSCH.

(Wochenschrift des Vereines deutscher Ingenieure, 1880, p. 346.)

The subject of gaseous fuel, in the Author's opinion, will daily demand more and more attention, as its present application to the manufacture of glass, iron, and steel is now being extended to the generation of steam, &c. He considers that hitherto regard has been paid rather to the combustion of the gas than to its production, which remains in much the same condition as it has been for the last thirty years. The Author gives the well-known theory of the gas-producer, in which carbonic acid is first produced, and is then reduced to carbonic oxide by passing through the unconsumed fuel, from which the hydrocarbons are distilled to enrich the gas. In this application it is necessary to distil the tar, either by means of cold water, or by the use of overhead tubes as employed by Dr. Siemens (but in any case the large quantity of nitrogen imported into the gas diminishes its heating effect), or by means of a shoot of variable height, preventing the production of tar. A modified form of generator, in which the gas is drawn from a low level, the air entering from above through the charging-box, and the ashes being removed from below, is referred to as a form that has been adopted in Sweden for converting wet fuel.

Three forms of producer, with the object of generating permanent non-condensible gases, are described. In one form air is supplied both from above and below; the gas channel surrounds the centre portion of the producer, and is supplied through openings in the same. In this way all the gaseous contents of the fuel are utilized, the gases being distilled in the upper portion, and carbonic oxide formed in the lower portion. In the others a retort

action is attained, the difference consisting in the one employing waste heat for gasification, and the other a portion of the gasified products.

Two arrangements are next described for the production of heating gas free from nitrogen, the one by the Author, and the other the Strong process. In the former two rows of retorts, each with central tubes to carry off the gas, filled above at the sides, and with the ashes removed below at the side, are heated by means of ovens worked on the regenerative principle. After distillation is complete, a steam jet is turned on, and carbonic oxide is thus added to the other gaseous products.

In the Strong process the fuel is supplied to a narrow and deep chamber, having a grate below; by the side of this is a regenerative chamber, filled with a network of fireproof bricks, whilst another vertical and narrow chamber is supplied with a steam-jet to produce a draught. When the regenerative chamber is at a proper heat the draught is stopped, and steam is forced in, which is resolved into its elements by the great heat of the regenerative chambers, passes through the glowing fuel, and passes away by a gas channel below the fire-grate to a gas-holder.

The Author concludes by stating that as the cost of fuel is considerably enhanced by carriage, and by passing through the hands of middle men, whilst its value is injured by the rough treatment it receives, the supply of fuel in the gaseous, instead of in the solid form, is only a question of time.

E. F. B.

Petroleum as Fuel. By S. Gulishambarof.

(Gorny Journal, June 1880.)

The Author gives a table, compiled from St. Claire Deville's papers published in the Comptes Rendus, vol. lxvi., pp. 442–453, and vol. lxxii., p. 193, showing the depth of the wells, the specific gravity, the percentages of carbon, hydrogen, and oxygen, the coefficient of expansion, the practical and theoretical evaporative powers of forty-seven specimens of naphtha collected from all parts of Europe and North America. From the table it appears that the Caucasian naphtha contains rather more carbon and a little less oxygen than other varieties, and has therefore a higher calorific value.

In the Caucasus the refuse alone from the distilleries used to be employed as fuel, because it was not only useless for other purposes, but had to be got rid of as a waste product. As recently as 1874 it could be had for nothing, and in any quantity. In 1875 the price was about 3*d.* per barrel of 720 lbs. weight; in 1876 the price was 1*s.* per barrel; in 1877 the cost rose to 2*s.*; and in 1879 it could not be obtained for less than 5*s.* 3*d.* per barrel; while the raw naphtha could, at the same period, be purchased for 10*d.* per

barrel. Up to the present time it may almost be said that naphtha refuse alone has been employed for heating purposes, but it is quite evident that serious attention must be directed to the use of raw petroleum, of which there is a much greater supply than is needed for the manufacture of illuminating oils, and which still continues to fall in value.

Much has already been done by Lenz and others in this direction, but there is a strong opinion, or rather prejudice, abroad that the use of raw naphtha is accompanied by great danger from explosions, and from spontaneous combustion, and these illusions have been fostered by Professor Lissenko and others having a scientific reputation. The liability of raw naphtha to catch fire in consequence of the very volatile oils it contains is easily reduced to safe limits by exposing the naphtha to the atmosphere for a few days, after which it may be stirred with a glowing stick without any risk of fire. In summer the change takes place more rapidly than in winter, the loss of weight reaching to 15 per cent. in from two to three days, but in winter, by slight heating, the same result may be obtained.

On the Balachanskoi railway the locomotives are fired with raw naphtha, which is poured into the tenders direct from the springs, and yet there has never been an accident of any kind.

Another objection urged against the use of raw naphtha is that it yields less duty in consequence of the length of the flame produced being in excess of the length of heating surface; this, however, is obviously a difficulty which may easily be got over.

The other objections are all more or less connected with the supposed dangers from fire or spontaneous combustion. It is notorious that many kinds of coal are liable to spontaneous combustion, whereas petroleum cannot catch fire spontaneously at ordinary temperatures. The vapour arising from naphtha can only be fired by contact with flame, and an explosion can only take place when mixed with at least 8 per cent. of air.

On the 9th September, 1870, an explosion of petroleum occurred on board a lighter lying in the Cronstadt Roads. The Ministry of Marine instructed the Academy of Sciences to investigate the matter, and the Committee reported as follows.

No authentic case of spontaneous combustion of naphtha had come under their notice. The component parts of naphtha do not absorb oxygen from the atmosphere, oxidise very slowly when exposed to the air, and resist the action of strong reagents. Hence, if spontaneous combustion is possible, it can only be when finely-divided combustible substances are wetted with petroleum and allowed to lie in large heaps.

Raw naphtha contains oils more volatile than kerosene, hence it is more easily set on fire than that substance.

In consequence of the volatile nature of some of the constituents of petroleum it may be set on fire from a distance, and if the vapours are mixed with the proper proportion of air an explosion may take place.

In Richardson's opinion a red-hot shot falling into a tank of naphtha would not cause an explosion, but simply evaporation; and the Author has himself seen, in the Caucasus, burning logs quenched in petroleum instead of water without setting the oil on fire.

The Author next gives tables of the calorific value of different kinds of solid fuels, and shows that naphtha is superior to all, and is distinguished from most by its freedom from sulphur and other injurious impurities. He points out that not more than 60 per cent. of the theoretical heating power of solid fuels can be realised, while according to St. Claire Deville and Rankine 90 per cent. of the theoretical evaporative power of petroleum can be secured; the conclusion consequently is that 1 lb. of petroleum should be worth 2½ lbs. of coal; but this result has not yet been realised in practice for several reasons, such as the use of excessive draught, imperfect combustion for want of air, the admixture of water, reaching up to 5 per cent. in the naphtha.

The cause of explosions in furnaces fed by injectors is next considered, and the relative advantages of steam and air injectors are discussed. The prejudicial effect of naphtha on the furnaces of boilers the Author considers has been due to improper arrangements of the injectors. The flame should be kept as short as possible, and its hottest part as near to the jet as may be, because the boiler-plates only suffer where a very intense flame is allowed to impinge.

In the year 1869 one of the Russian naval papers doubted whether petroleum could ever be used as fuel on board ship. At the present moment the whole of the steamers, both commercial and war, on the Caspian, use exclusively liquid fuel, the consumption of which appears to be from 4·5 to 4·9 lbs. per HP. per hour, against from 10 lbs. to 10·8 lbs. of coal under the same conditions; in other words, the steamers using oil need carry only half the weight of fuel.

From experiments made on the Baku-Balachan railway on the relative merits of oak firewood and oil in locomotives, it would appear that 1,080 lbs. of naphtha are equivalent to 343 cubic feet of wood, or 1 lb. of naphtha is equal to 8½ lbs. of wood, although theoretically it should equal only 3 lbs. Petroleum fuel when used with injectors is remarkably under control; the rate of evaporation of a boiler can be altered at pleasure by adjusting the flow of oil and air, and this advantage is found of great practical value in locomotives. The difficulty of lighting the fires when there is no steam to work the injectors is a disadvantage, but the freedom of petroleum from sulphur, and the circumstance that there is no occasion to open the furnace doors, leads not only to the efficiency of the fuel, but also to the durability of the furnaces. There is naturally much less labour in firing, and a complete absence of sparks, smoke, and ashes.

The Author finishes an interesting Paper by examining the prospects of the naphtha industry, and is of opinion that the supply

of petroleum in the Russian Empire, and especially in the Caucasus, is inexhaustible.

A diagram is annexed showing the progress of the industry in the Caucasus during the last fifty years.

W. A.

On the Manufacture of Charcoal in Kilns. By T. EGLESTON.

(Transactions of the American Institute of Mining Engineers, vol. viii., p. 373.)

The production of charcoal in the United States has been studied almost exclusively in view of the smelting of pig-iron in the blast furnace; but for this purpose it is rapidly becoming of minor importance. There are, however, many processes, such as those producing malleable iron blooms directly from the ore, and the smelting of lead and silver ores, in which it is likely to continue as a furnace fuel, and where density of product is of less consequence than freedom from silica and other mineral impurities. In such processes, and in regions where no other fuel can be obtained, the kiln is of peculiar importance as giving a larger yield from the same amount of wood than can be obtained by the meiler or pit-burning process. The kilns used in the United States are of three principal patterns, namely, rectangular, round and conical. The first of these is essentially a rectangular chamber with an arched roof from 40 to 50 feet long, 12 to 18 feet wide, and about the same height to the springing of the roof, and about 5 feet more to the crown of the arch. The capacity varies from 55 to 90 cords of wood, and the latter size will yield under favourable circumstances about 4,000 bushels of charcoal. There are two doors about 5 feet square in each of the end walls; the upper one serves for charging the wood, and the lower for discharging the charcoal. Three series of vent holes, at about 1 foot vertical distance, and about 16 inches apart, are left in the lower part of the walls for the introduction of the air necessary for combustion and to allow of the escape of the products of distillation. The wall is 1½ brick thick, strengthened at intervals by buttresses and iron or wood bracings and tie-rods. The wood of the charge is usually cut in four-feet lengths, and piled flat as closely as possible, four men working one day being required to fill a 45-cord kiln. After firing, the doors are closed, the joints being carefully luted with lime mortar, which is also used in closing the vents when the condensable products of distillation have escaped. The kiln may be lighted in several different ways, as, for instance, by a chimney left in the wood in the centre, which is one of the best methods, or by a channel built through the middle, having an opening at each door, and filled with dry wood and shavings, which is fired from the back. This is known as the centre burn. The operation is easily and regularly conducted, provided the walls are tight. The smoke first issuing is yellow, and becomes blue about the

fourth, fifth or sixth day, when the vents must be successively closed. From four to eight days are required for cooling. This is sometimes accelerated by quenching with water, which, however, deteriorates the charcoal to some extent. The whole charge can be drawn by four men in one day. From 6 to 10 per cent. of imperfectly burned wood or brands are found upon the floor; these are either returned to the next charge or used for special purposes in the works.

The rectangular kiln is going out of favour from the difficulty of keeping it tight when of large size, and smaller sizes are not economical in work. The weight of charcoal produced varies with the hardness of the wood, the softest kind, white pine, being 9·81lbs., and the hardest, sugar maple, 18·95 lbs. per bushel.

The second, or round pattern of kiln is a cylindrical or very slightly coned chamber, about 28 feet in diameter, 12 feet high, covered by a spherical domed roof of 6½ feet rise, and 16 feet radius, and braced with wrought-iron rings. There are two principal openings, a circular one about 5 feet diameter in the top of the roof, and a rectangular one at the ground level; the bulk of the charge is introduced, and the whole of it is drawn through the latter, the former remaining for filling up the higher part of the chamber. The filling is commenced by placing skids, or pieces about 6 inches diameter, radially on the floor, with interstices for air channels, above which about 2 feet of dry wood and brands are placed, leaving a space in the centre, about 4 feet in diameter, for a chimney, which is carried to the top of the kiln. The wood is piled horizontally and packed as closely as possible. When no more can be put in at the lower door, it is closed, and the filling is continued in the same way from above. Shavings and light wood are then charged loosely into the chimney, or sometimes this is done as the piling proceeds. From four to five men can fill a 45-cord kiln with 4-feet cord wood in a day. With long butts, a 35-cord kiln can be filled in twelve hours, as they require less handling.

The firing is effected by a long torch through the bottom door, through the spaces left by the skids. According to the size of the kiln, from six or seven to ten or twelve days are required for burning. After all the vents have been closed, from four to six days are required for cooling, and one day for drawing.

The objection of want of stability made against the rectangular kiln applies with still greater force to round ones, which require to be hooped with iron in addition to bracing. They are therefore being rapidly given up in favour of the more economical conical forms, which are usually made of less capacity than either of the preceding varieties. The leading dimensions are from 25 to 35 feet in diameter at the base, and 20 to 25 feet high, taking from 25 to 45 cords of wood, the construction being such as to require no bracing of any kind. Three different patterns are described, the differences being, mainly in the slope of the side of the wall, which is in some cases a single cone; in the second a combination of two, the

flatter forming a roof to the steeper one; while in the third the wall is only conical to a height of 6 feet, the remaining 14 feet being curved to the arc of a circle. The doors are arranged, and the charging and burning are conducted in a manner generally similar to that described for the round kiln. One of 35-cord capacity requires one day for charging, four days for burning, three days for cooling, and one day for discharging. The yield of charcoal in the best conducted works is about 50 bushels per cord, though in some cases with hard wood it may be as high as 60 bushels. The cost of the conical kiln is from 500 to 600 dollars, according to the price of bricks in the locality, from 35,000 to 40,000 being required. It is desirable in all cases to face the vents with cast-iron, as without such protection to the bricks the pyroligneous acid attacks the mortar, which falls first around the brick and then above it, producing cracks of considerable size which it is almost impossible to fill. The additional cost of the cast-iron vent-holes is about 75 dollars per kiln, which is more than saved in the cost of repairs in a few years.

In the silver smelting works of Utah the charcoal used, being made from poplar wood, which is cut dead, is very soft and light and crushes very badly, producing a great loss in fine charcoal during carriage. The use of such woods is, however, partially justified by the fact that the cost of coke delivered at the lead furnaces of this locality is 45 dollars (£9 7*s.* 6*d.*) per ton.

H. B.

On the Microscopic Structure and the Crystallization of Pig-iron, especially of the grey variety.

B. A. MARTENS, Engineer, Berlin.

(Zeitschrift des Vereines deutscher Ingenieure, vol. xxiv., p. 397.)

Liquid cast-iron may be considered as a solution of various substances, both solid and gaseous, in liquid iron. Some of these are chemically combined, while others are merely mixed with or suspended in it, and the form they assume in the solidified metal depends upon the manner of cooling.

The process of solution and separation is analogous to that which takes places in water, which, according to its temperature and capacity for holding in solution, separates, in cooling, substances held in solution one after the other.

Some kinds of iron, as they run from the blast furnace, eject graphite in the form of sparks or slag, while the occluded gases escape in the form of flame or form bubbles. As the mass cools, the separation of the dissolved substances takes place internally, and a tendency to segregation of similar substances becomes apparent, and the change of structure thus produced continues

cut-off is approximately given by means of the second lever in the large cylinder.

It will be seen that these arrangements fulfil the conditions laid down above. A compound engine on this system, as compared with an ordinary locomotive, has not only the common advantages of the compound engine (especially the avoidance of great changes of temperature within the cylinder), but has others peculiar to itself. A locomotive is comparatively seldom under its maximum load, and therefore should generally be worked with a high grade of expansion. But where this is given in a single cylinder, and by the ordinary slides, there is so much wire-drawing at the beginning, and compression at the end of the stroke, that economy of working is sacrificed. By dividing the expansion between two cylinders, and thus having a far lower grade in each, this evil is done away with. Again, the longer maintenance of the full pressure within each cylinder places the useful work in a much more favourable relation to the engine friction—a quantity which, especially with 6-coupled and 8-coupled locomotives, is considerable. The net pressure on the slides, and therefore their friction and wear, is also diminished by one-half; while, since the total pressure in the large cylinder is never materially greater than in the small, the dimensions of the piston-rod and other working parts may be the same in both.

As the result of his system, the Author estimates that a saving in fuel of at least 15 to 20 per cent. may be reckoned upon. He is now building four sister engines, two on the ordinary plan, and two on the new compound system, and hopes soon to publish the results of comparative experiments between them.

W. R. B.

Recent Legislation on Steam Boilers in France.

(Société Scientifique Industrielle de Marseille, 1880.)

By a recent decree of the President of the French Republic, dated April 30, 1880, the Government regulations for stationary, portable, and locomotive steam boilers, passed in 1865, have been modified and adapted to more modern experience. There is no change in the essential conditions of the proving of new boilers, but boilers are now to be proved at least once in ten years, as well as after every important repair. The most important innovation in the new law is its extension to steam-chambers or reservoirs having a volume greater than 100 litres, or 3½ cubic feet: such as drying cylinders and heaters with double bottoms, also fireless locomotives.

The proof, which is made under the direction of an engineer of mines, consists of hydraulic pressure, equal to twice the effective working pressure; but the excess pressure is never to be less than half an atmosphere, nor more than 6 atmospheres. The limit of

working pressure, expressed in atmospheres (kilogrammes par centimètre carré) on a stamp, dated, affixed to the boiler. Each boiler is to be fitted with two safety-valves, to blow off at such a pressure that the authorised limit of pressure may never be exceeded. A pressure-gauge is to be attached to the boiler. A check-valve is to be attached to the feed-pipe. A shut-off valve or cock is to be fixed on the steam-pipe, as near as may be practicable to the boiler. Fire-heated plates are to be covered by at least $2\frac{1}{2}$ inches of water, excepting in the case of superheaters distinct from the boiler, or of chimneys traversing the steam-space. Two gauges for water-level are to be provided, one of them being a glass gauge.

Steam boilers are to be registered at the prefecture. They are divided into three categories based on the product of the total capacity of the boiler (including feed-heaters), in cubic mètres, by the excess temperature, in centigrade degrees, of ordinary steam at the authorised pressure above 100° Centigrade. For two or more boilers in communication, the total capacity is taken as the factor. For the first category, the product exceeds 200; for the second, it does not exceed 200, and is greater than 50; for the third, it does not exceed 50.

Next follow the conditions for boilers which are placed near dwelling-houses. For boilers in mines, special provisions are made by the local prefect on the report of the Engineer of Mines.

D. K. C.

Non-condensing Compound semi-portable Engine.

By MM. CHALIGNY and GUYOT-SIONNEST.

(Annales Industrielles, August 29, 1880, col. 273.)

Two semi-portable engines, with compound cylinders, have been constructed for the French naval service. On a boiler of the locomotive type, the engine is placed horizontally as in ordinary semi-portable engines. The cylinders are respectively 11 inches and 19 inches in diameter, with a stroke of $17\frac{3}{4}$ inches. They are connected to cranks at right angles, and have an intermediate receiver for the steam from the first cylinder, from which it is delivered to the second cylinder. The steam is exhausted from the second cylinder into the atmosphere by the chimney. The capacities of the cylinders are as 1 to 3; the capacity of the receiver is $1\frac{1}{3}$ time that of the first cylinder. The steam is cut off in the first cylinder at from $\frac{6}{10}$ths to $\frac{8}{10}$ths of the stroke, and in the second cylinder at $\frac{6}{10}$ths: expanding the steam by from $3\frac{3}{4}$ to 5 times. The engine makes ninety turns per minute. The power at the brake, for steam of a pressure of 75 lbs. per square inch, expanded 5 times, is 42 HP.; expanded $3\frac{3}{4}$ times, the power is 55 HP.

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It will be seen that these arrangements fulfil the conditions laid down above. A compound engine on this system, as compared with an ordinary locomotive, has not only the common advantages of the compound engine (especially the avoidance of great changes of temperature within the cylinder), but has others peculiar to itself. A locomotive is comparatively seldom under its maximum load, and therefore should generally be worked with a high grade of expansion. But where this is given in a single cylinder, and by the ordinary slides, there is so much wire-drawing at the beginning, and compression at the end of the stroke, that economy of working is sacrificed. By dividing the expansion between two cylinders, and thus having a far lower grade in each, this evil is done away with. Again, the longer maintenance of the full pressure within each cylinder places the useful work in a much more favourable relation to the engine friction—a quantity which, especially with 6-coupled and 8-coupled locomotives, is considerable. The net pressure on the slides, and therefore their friction and wear, is also diminished by one-half; while, since the total pressure in the large cylinder is never materially greater than in the small, the dimensions of the piston-rod and other working parts may be the same in both.

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reaction, and which in two cases had the following composition:—

—	CO.	CO_2.	N.	H.	O.	Total.
Analysis No. 1 . .	82·6	..	14·3	2·8	..	99·70
„ No. 2 . .	78·55	0·86	16·38	2·52	1·32	99·63

It will be seen that hydrogen was present, and in about the proportion demanded by the theory; so that in fact CO is not only innocent of the production of cavities in steel, but may actually be used to prevent them.

Another mode of attaining this end would be by thoroughly drying the air before blowing it through the metals, so as to stop the introduction of hydrogen. This could be done by using burnt lime, with little expense. The nitrogen would of course remain, but it is uncertain whether this, by itself, would be harmful.

These discoveries of the Author were subsequently criticised by M. Pourcel, who suggested that the hydrogen was due to the ingot having been quenched from a red heat in water; that the water had penetrated into the cavities and decomposed, the oxygen going to oxidise the walls, while the hydrogen remained. This criticism, however, falls to the ground, because the ingots were not quenched as suggested.[1] In fact this could not have been done without making the steel too hard to bore. Moreover, although red-hot steel will decompose steam, there is no reason to suppose that it will decompose cold water; *e.g.*, there is no evidence that hydrogen exists in quenched iron. Nor is it easy to see how hydrogen so formed could have found its way into the interior cavities of the ingot, and certainly not under a pressure of 7 atmospheres. It would seem as if the French metallurgists were thinking only of the central cavity, which is open to the atmosphere, and which, of course, was not under consideration at all.

W. R. B.

The Losses in Copper Dressing at Lake Superior.

By H. S. Munroe.

(Transactions of the American Institution of Mining Engineers, vol. viii. p. 409.)

The native copper of Lake Superior occurs in two principal conditions, namely, in masses of all sizes, up to at times several hundred tons weight, and disseminated through rock in smaller

[1] In his preliminary report to the German Chemical Society, Dr. Müller mentions that the ingots were cooled in water: it is to be understood therefore that this cooling was not begun till their temperature had fallen too low to admit of hardening. -W. R. B.

particles, from a few pounds down to 5 grains, and scales. The latter, forming the so-called stamp-rock, is by far the most important product of the mines. It is also observed that the copper of the conglomerate beds is, for the most part, in the condition of fine flat scales and leaves, in the amygdaloidal lavas it is comparatively coarse, and in the so-called ash beds the particles are of intermediate sizes to the preceding. Thus, in the conglomerate, about 65 per cent. of the total contents are in particles below $\frac{1}{25}$ inch in diameter; in the ash bed of the Atlantic mine there is but 42 per cent. of equally fine copper, and in the amygdaloid from Quiney mine only 10 per cent. These great differences in the proportion of coarse and fine copper in the products obtainable from the different mines explain the differences in the assays of tailings from the mills working different classes of rock, the amount of copper being proportional to the fineness of the particles.

It is a commonly received opinion upon the lake that a large portion of the loss is due to the formation of suboxide of copper during the operation of dressing. This point has been investigated by the Author in considerable detail, the various intermediate products of the dressing operations having been tested by treatment with a neutral solution of nitrate of silver, which dissolves the clean metallic particles, while the oxides and other compounds of copper are not acted upon. The latter may, however, in many cases, include particles of copper so inclosed in the silicious matrix as to be inaccessible to the solvent, and therefore the results are not quite conclusive. Subject to such correction, however, the Author gives the following results:—

Samples Tested.	Percentage of—		
	Metallic Copper.	Oxide of Copper.	Total Copper.
Freshly mined rock, Atlantic mine . . .	1·54	0·14	1·68
Sand from stamps, „ . . .	0·70[1]	0·78	1·48
Tailings from Evans table, Osceola mine .	nil	0·53	0·53
Heads „ „ „	24·23	8·40	32·63
Waste sand from lake, „	nil	0·49	0·49

[1] Result marked as doubtful.

From these results it appears that the amount of oxide of copper in the freshly-mined rock is very small, and that by exposure for several months in the mine the proportion is increased until half the copper in the rock is oxidized. The assay of the heads from the Evans table shows, however, that a large part of the oxide is actually saved in dressing the slimes. This change, due to exposure, leads to the inference that the rock should not be left uncovered in the mine too long, or broken into too small fragments

in stoping. The Author suggests that the "Hercules" powder, used in many of the copper mines, contains an excessive proportion of nitrate of soda, which may act prejudicially in oxidizing copper in the rock.

The methods of dressing are next discussed with reference to the losses in the different steps of the process, reference being made for details of the apparatus to the memoirs published by Professor Egleston and others. The ultimate result, calculated from the average return of smelting works and other details, gave the following figures as the approximate amount and percentage of metallic copper obtained as mineral, and lost in the tailings at different mills, in the treatment of 1,000 tons of copper rock.

Tailings.	Tons of Rock.	Yield, Copper.	Yield per cent.	Copper in Tailings.				Loss per cent.
				Included	Free.	Included	Free.	
Calumet Mill, Conglomerate.		Lbs.		Per cent.		Lbs.		
Sand, coarse or fine.	650	86·800	9·64	1·43 1·10	2·54	16·048	18·780	28·00
Slimes	350	4·200	0·60	0·56	0·50	3·920	2·100	60·00
	1,000	90·000	4·50	0·998	1·044	19·968	20·880	31·00
Osceola Mill, Conglomerate.								
Rough sand . . . Hutchwork sand .	546	32·800	3·00	1 05		11·465		25·9
Slimes from tables .	294	2·400	0·41	0·50		2·940		53·2
„ overflow . .	160	nil	nil	0·40		1·280		100·0
	1,000	35·200	1·76	0·78		15·685		31·0
Atlantic Mill, Ash bed.								
Rough sand . . .	350	17·950	1·632	0·425		2·975		21·3
Hutchwork sand .	200			0·470		1·880		
Slimes from tables .	270	1·250	0·231	0·460		2·484		66·5
„ overflow . .	180	nil	nil	0·200		0·320		...
	1,000	19·200	0·960	0·383		7·659		28·5

Of the total copper lost in the tailings at the Osceola mill, not more than one-tenth, or about 1,500 lbs. per 1000 tons of rock is float copper, while at the Calumet mill fully one-half of the loss is in the tailings, the difference being chiefly due to the imperfect slime treatment in the latter case.

In summing up the results of his observations, the Author points out that the losses in the form of float copper are to be remedied by simple modification or arrangement, and by increasing the number of jigging machines and slime dressing tables. If any important loss can be traced to oxidation, the methods of mining

must be modified; but if, as seems more likely, the loss is principally due to included particles of copper escaping with the waste, the remedy will lie in the fine crushing of the sands, with or without previous concentration, by jigging or slime washing. The apparatus in use seems admirably adapted to the work, and but few changes are to be recommended; but the introduction of some improved classifier, to replace the hydraulic separator now used in sizing the discharge from the stamps for the jigging process, seems imperative. By giving greater speed to the fine sand jiggers, or better, perhaps, by replacing them by Evans tables, the capacity of the mill will be increased, and the cost of dressing lessened. If more of these tables be used, it will be advisable to have them in two series, one for sands and the other for slimes, the stuff fed on them being previously classified by pointed boxes. The treatment of low grade minerals is a problem of greater difficulty. These consist of sands with muck included, and float copper, iron-sand, and other heavy minerals. The effect of passing such material through Hodge's conical grinding mill, which is figured and described in the Paper, or some similar machine, would probably be to release most of the included copper, roll up and condense the light float copper into sheets or cigar-shaped pellets, and crush the iron-sand, and heavy minerals, giving a product which should present no difficulties in the subsequent concentrating treatment.

H. B.

The Gold Mines of the Höhen Tauern.

By F. Pošepný.

(Archiv. für practische Geologie, vol. i., p. 1.)

The Author, in this memoir of 256 pages, gives the results of an investigation into the structure and character of the gold-bearing deposits of the Alpine district known as the Höhen Tauern, in Salzburg, Tyrol, and Carinthia, which was undertaken at the request of the Austrian Government, in 1876. Although now comparatively unimportant as gold-producing centres, these mines are of great interest historically, the data concerning the workings extending back to the middle of the 16th century. The principal mines are those of Rauris-Goldberg, and Rathhausberg, near Gastein in Salzburg, and Zell in the Zillerthal in Tyrol.

Rauris.—These mines are probably the highest in Europe, the lowest workings accessible in the year 1870 being 7,544 feet above the sea-level, and the highest 8,869 feet. There are four parallel groups of quartz lodes, striking nearly north and south, and across the bedding of the gneiss country, the bearing portions being limited between slaty bands, locally called *Neuner*. The mouths of some of the lower levels are now completely blocked by a glacier, which there is some reason to believe has

carried the spoil heap of the 16th-century miners about 200 yards away from its original position. The dressing floors in the Rauris valley at Kulm Saigurn are connected with the mine by an inclined plane having a vertical lift of 1,870 feet, worked by a water-wheel. The nearest productive workings are about ⅗ths of a mile from, and 567 feet above, the top of the incline. The vein stuff or quartz contains gold very frequently interspersed with pyrites and occasional silver and antimony ores. The largest yield appears to have been in the decade 1670–79, when it averaged 37·4 grammes (about 1 oz. 3 dwt.) per ton. In the latest years for which returns are given, 187–375, the amount had diminished to 12 grammes, extracted by the Tyrolese mill from the stamp stuff, worth 25*s.*, a further amount, equal in value to 8*s.* 9*d.* per ton, being obtained from the pyrites and other dressed ores. These returns were not sufficient to cover the cost of working, which has been stopped, as most of the ore discovered had been removed. The Author, however, considers that a deeper level might be driven with advantage, which would lay open new ground to a depth of 557 feet below the present bottom of the mine.

Rathhausberg.—This includes a great development of workings upon a lode about 2,187 yards long, which has been followed to a depth of about 1,640 feet in the mountain known as the Rathaus Kogel of Gastein. The mountain is completely riddled by the levels which cross from side to side. The total length driven was about 28 miles in 1841, and of these rather more than one-fourth are older than the year 1570. What the production may have been in these earlier times is not known for certain. In 1589 the original company broke up, and the works passed into the possession of the Archbishop of Salzburg, who was succeeded in 1803 by the Austrian Government, and in 1864 by a private company. The stuff stamped is extremely poor, and varies very irregularly. About one-half of the contained gold is free or can be extracted by amalgamation in mills, the other half, combined with about six or eight times its weight of silver, being recovered in smelting the dressed ore. The yield per ton for the last thirty-seven years has varied from 3 to 9 grammes (2 dwt. to 5½ dwt.).

Zell in Tyrol.—The mines of this district, which are now completely abandoned, were worked upon a bed-like mass of quartz in crystalline schist and limestone, yielded, in the latter years of working, about 4 dwt. per ton, which was too poor to give any profit.

In conclusion the Author compares the phenomena observed in these deposits with those of other regions, more particularly with Hungary, Transylvania, Brazil, and California, and discusses the hypothesis of the probable cessation of gold-bearing veins in depth, which he does not consider to apply to the districts here described.

H. B.

The Relation of the Thermal to the Electrical Conductivity of Metals. By H. F. Weber.

(Monatsbericht der K. P. Akademie der Wissenschaften zu Berlin, 1880, p. 457.)

Forbes in 1831, and later Wiedemann and Franz, published experiments on the ratio in question, showing it to be a constant quantity; similarly Neumann, from absolute measurements on copper, brass, zinc, German silver, and iron, obtained respectively the following values: 17·5, 19·8, 17·1, 19·9, and 18·9, and considered the value to be constant, ascribing the difference in the above numbers to errors of observation; and to the like conclusion arrived Lenz from his experiments on the same metals. Now this is certainly at variance with our accepted theory of heat, which requires that the thermal conductivity of a metal should be a function of its specific heat referred to unit of volume. For gases and liquids this dependence holds good, and as the specific heats of the metals above mentioned are nearly equal in value, the results therefrom obtained can neither contradict nor corroborate the theory. The Author has, therefore, carried out a complete series of determinations of both conductivities for several metals; and in order that the very same piece of the substance should be used in both cases, the following methods were chosen. The thermal conductivity was calculated from the rate of cooling of a ring of the metal in question, and the electrical conductivity from the damping action of the same ring on a magnetic needle in its proximity. In this way were obtained the values for copper, brass, zinc, silver, cadmium, and tin; for lead, Wood's metal, and bismuth, owing to their inferior conducting powers, a somewhat different method being used.

The appended Table gives the values obtained in absolute measure for each metal, those in the last column being obtained from the formula $\frac{k_0}{K_0} = a + b.\,c_0$, where $a = 0{\cdot}0877 \times 10^4$, and $b = 0{\cdot}1360 \times 10^4$. The close agreement between the numbers in

—	Specific Heat. C_0.	Conductivity. Thermal. k_0.	Conductivity. Electrical. K_0.	$\frac{k_0}{K_0}$.	$a + b.\,c_0$.
Copper	0·827	0·8190	$40{\cdot}81 \times 10^{-5}$	$0{\cdot}2007 \times 10^4$	$0{\cdot}2002 \times 10^4$
Brass.	0·791	0·1500	7·62 „	0·1968 „	0·1953 „
Zinc	0·662	0·3056	17·43 „	0·1753 „	0·1777 „
Silver	0·573	1·0960	65·87 „	0·1664 „	0·1656 „
Cadmium . . .	0·475	0·2213	14·61 „	0·1515 „	0·1523 „
Quicksilver . . .	0·441	0·0152	1·047 „	0·1452 „	0·1475 „
Tin	0·380	0·1446	10·34 „	0·1398 „	0·1394 „
Wood's metal . .	0·371	0·0319	2·313 „	0·1379 „	0·1373 „
Lead.	0·340	0·0719	5·351 „	0·1345 „	0·1339 „
Bismuth. . . .	0·293	0·0108	0·838 „	0·1288 „	0·1275 „

the last two columns, and the wide differences in their value, establish without further comment the care with which the determinations have been made, and the truth of the theory. The values are reduced to 0° Cent., and as k and K do not decrease equally with the temperature, a and b are probably functions of the temperature.

F. J.

On the Thermo-electric Power of Iron and Platinum in Vacuo.

By Prof. C. A. Young.

(American Journal of Science, Nov. 1880, p. 358.)

Exner asserts that the thermo-electric power of antimony and bismuth is destroyed by removing them from all contact with oxygen, and immersing them in an atmosphere of pure nitrogen. From this he argues that the thermo-electric force in general is due to the contact of the gases which bathe the metals. The following experiment was tried to test the theory.

By the kindness of Mr. Edison and Mr. Upton a vacuum tube was prepared in Mr. Edison's laboratory, containing an iron wire, about 2 inches long, firmly joined to two platinum terminals which passed through the walls of the tube; the tube was exhausted until a spark from a 2-inch induction coil would not pass $\frac{1}{8}$th of an inch in the gauge-tube, indicating a residual atmosphere of about one-millionth. The wire was heated to incandescence during the exhaustion in order to drive off any possible occluded gases. The platinum wires outside the tube were joined to iron wires, the joinings being covered by glass tubes slipped over them, and a sensitive deflecting galvanometer was included in the circuit. By laying the tube and connecting joinings in the sunshine, and alternately shading over one or several of the joinings, it was found that the electro-motive power of the joinings within the tube was precisely the same as that of those without, and the development of current just as rapid. There was no trace of any modification due to the exhaustion.

A New Recording Galvanometer. By G. M. Hopkins.

(Scientific American, Oct. 30, 1880.)

This instrument consists of an ordinary astatic galvanometer of the vertical form; the pointer is made of aluminium, and prolonged beyond the scale, so that its extremity when bent at right angles presents a fine point in close proximity to the surface of a brass cylinder, which is mounted on suitable supports, and capable of rotation about its axis, the rate of which may be varied according

to the nature of the observations desired. The needle, by means of its pivots, is put in connection with one terminal of an induction coil, and the brass cylinder with the other, so that, on the coil being set in action, a continuous series of sparks pass between the point and the cylinder. A paper scale, divided in one direction in degrees, and in the other in hours and minutes, the latter being curved to correspond with the arc traversed by the pointer, is placed on the cylinder, and the perforations caused by the electric sparks preserve a record of the path travelled by the pointer. Copies of this record may be multiplied by using the one originally obtained as a stencil plate. This apparatus is designed for the continuous testing of batteries; but the method of recording here employed may be applied to any species of registering instruments, as barometers, thermometers, &c.

F. J.

[NOTE.—The method of recording the changing position of a galvanometer needle, by perforations produced by electric sparks, was patented by Sir William Thomson in 1858, for application to signals through a submarine cable. An instrument realizing the idea was shown at work at the Royal Society in London, about the year 1860, and exhibited at the Loan Exhibition of Scientific Apparatus at South Kensington in 1876.—SEC. INST. C.E.]

A Graphical Method for Determining the Form of Galvanometer Coils of Greatest Sensitiveness. By T. EDELMANN.

(Carl's Repertorium für Experimental-Physik, vol. xvi., p. 670.)

This method is applicable to mirror-galvanometers wound with circular coils; a space of 12 millimètres (0·5 inch) being allowed about the axis for the mirror-suspension. If r is the radius of a single winding, and e the perpendicular distance of its plane from a short magnetic needle, the effect of that winding traversed by a current of unit intensity is, according to the well-known law—

$$y = \frac{2\pi r^2}{(e^2 + r^2)^{\frac{3}{2}}} \quad . \quad . \quad . \quad . \quad \text{(I.)}$$

If it be further considered that each winding introduces a resistance proportional to $2\pi r$, this expression for a given electromotive force becomes—

$$z = \frac{r}{(e^2 + r^2)^{\frac{3}{2}}} \quad . \quad . \quad . \quad . \quad \text{(II.)}$$

The Author has calculated the value of z for different values of e and r, and from these values plotted the curves for which z has a constant value; and which consequently give the boundaries of the sections of coils of greatest sensitiveness. By means of an

Amsler's planimeter the area of each curve was determined, and by his momentum-planimeter its centre of gravity, from which the cubic contents of each coil, and ultimately the length of wire one millimeter in diameter which would be required, were obtained. To sum up the magnetic effects of each zone, a second set of curves, corresponding to constant values of y in the first equation, was described superimposed on the first; the areas enclosed by two neighbouring ones of each set giving an approximately equal magnetic effect could thus be obtained, and then the total for each zone, and by addition of these the total for each bounding curve of form (I.). Next is obtained in tabular form the cubical contents and mean sensitiveness of each winding corresponding to coils of the above determined form. The resistance is now only required of wires of different diameters, the number contained in a square millimeter of section, and the ratio of the diameters of the bare and covered wires, which then give all that is necessary for winding the required galvanometer, introducing also the law that the resistance of the galvanometer should be to the external resistance as the diameters of the bare and covered wires.

By application of the values above obtained in tabular form, the magnetic effect of the same in a galvanometer for use with a given external resistance can be calculated by assuming different diameters of wire; choosing that which is most sensitive, the form of section in which the wire has to be wound, is obtained by interpolation between the curves of form (I.).

If the external resistance is very large, so that the galvanometer resistance may be neglected, the section of the winding would then be given by curves of form (II.), the wire being as thin as practicable, and the amount depending on the cost and size of the galvanometer. The Author adds that this method has been in use at his works, and gives in his Paper all the results of each step in tabular form, and the curves on a millimeter scale.

F. J.

On the New Action of Magnetism on a Permanent Electric Current. By E. H. Hall.

(American Journal of Science, Sept. 1880, p. 161.)

In the "American Journal of Mathematics" (vol. ii. p. 287) was given the account of an experiment which showed that in the case of a strip of gold leaf, the electric current, as distinguished from the conductor in which it flows, is acted on by a permanent magnetic force. This action has now been observed in other metals, the whole series of experiments being fully detailed. The metallic leaf, about 4 inches long by 1 inch broad, is attached to a strip of glass, clips at each end form connections for the permanent current, and two smaller ones, in connection with a sensitive reflecting galvanometer, are affixed to positions on each side of the

conductor such as to give suitable deflections; this plate is then placed at right angles to the lines of force of a powerful electro-magnet. When the magnetism is excited a permanent alteration of the deflection is produced on the galvanometer, showing that the magnetic force has affected the equipotential lines of the electric current in the conductor. Subjoined are the relative values of the action for the metals experimented on :—

Iron . .	− 78	Gold .	+ 6·8	Tin	+ 0·2 (?)
Silver .	+ 8·6	Platinum	+ 2·4	Nickel	+

If, however, the specific conductivities of the substances be taken into account, the values will be as follows :—

Iron . .	− 80	Gold .	+ 32	Tin	+ 0·15 (?)
Silver .	+ 57	Platinum	+ 2·6	Nickel	+

The action in the case of tin was very slight, if any at all; as regards iron, the action was opposite in direction to that in gold, which might be attributed to its magnetic properties, but in nickel which is also magnetic the action was in the same direction as in gold, and perhaps as powerful as for iron, but owing to the difficulty in obtaining a uniform sheet of the thin metal, no numerical value could be attached.

The Author's conclusions from his above-given experiments are that if E be the electromotive force of the permanent current in a longitudinal direction of the conductor, E^1 that due to the action of the magnetic field in a transverse direction, and M the intensity of that field, then $\frac{M \times E}{E^1}$ is not a constant quantity for all metals, nor for different plates of the same metal; but if the thickness of the plate be taken into account then $\frac{M \times V}{E^1}$ is approximately constant for the same metal, where V is found by dividing the cross section of the conductor by the strength of the current. The effect of this magnetic action on the lines of static induction in glass could not be detected or must have been less than $\frac{1}{160.000.000}$ of the product of the electric potential into the magnetic intensity of the field.

F. J.

On the Law of Electro-magnetic Machines. By J. JOUBERT.

(Comptes rendus de l'Académie des Sciences, vol. xci., p. 468.)

On Alternating Currents and the Electromotive Force of the Electric Arc. By J. JOUBERT.

(Journal de Physique, ix. p. 297.)

The only methods hitherto applied to the measurement of alternating currents have been such as involved the use of the calorimeter or electro-dynamometer, in both of which, and especially

the latter, it is difficult to prevent considerable heating. The Author has therefore made use of a Thomson's electrometer, and by suppressing the charge of the jar, and connecting one set of quadrants permanently to the needle, has rendered the deflection independent of the sign of the difference of potential between the quadrants and proportional simply to the square of that difference. Let the quadrants be put in connection with two points of the circuit of intensity I, the resistance between them being R, then

$$I\,R = v_1 - v_2;$$

if again between any other two points of the same circuit an engine be introduced capable of transforming electric into any other form of energy, and E its electromotive force, then

$$E + I\,R^1 = v_1^1 - v_2^1;$$

and the electric energy consumed between the latter points is

$$I\,(E + I\,R^1) = \frac{(v_1 - v_2)\,(v_1^1 - v_2^1)}{R};$$

which values can be furnished directly by two electrometers. With an alternating in place of a continuous current, the needle is always deflected in the same direction, and gives a value proportional to the mean of the squares of the successive values of $(v_1 - v_2)$. This is not identical, however, with the actual mean, which can be found only when the law of the variation of $v_1 - v_2$ is determined as a function of the time. This was effected for a Siemens machine in the following manner. The period between two reversals was divided into a certain number of equal parts, and contacts so arranged that during the continuous revolution of the machine the electrometer was in connection only during the time equivalent to one division, $\frac{1}{2000}$ to $\frac{1}{20000}$ of a second, and thus the potentials obtained for each division. The resulting curve for the intensity as a function of the time was a sinusoid, which was, however, displaced in the direction of rotation a distance equal to one-eighth of the period, which is due, the Author concludes, not to the retardation of magnetization, but to the "self-induction" of the coil, as it was constant for speeds of 400, 700, and 1,000 turns per minute. The primary current being of the form A sin x, the secondary current would be of the form B cos x, and the curve resulting from the two together would be of the form C sin $(x + y)$ differing from the original curve only in intensity and phase. The same curve was also obtained by a different method described below, only that in that case the curve was in the normal position, as the self-induction for each division was reduced to zero. From these experiments the following empirical equation for the mean intensity of the current was deduced:—

$$I = \frac{C}{(R^2 + m^2)^{\frac{1}{2}}},$$

where R is the total resistance in circuit, m is a constant depending only on the velocity of rotation, and therefore varying inversely to the duration of the period between the reversals, and C is equal to the maximum electromotive force divided by $\sqrt{2}$. The Author has also developed this equation theoretically from first principles. Suppose the machine in uniform motion, E the value of the electromotive force resulting from the primitive magnetic field, I the quantity of electricity put in motion during the time dt, then

$$E = I R + U \frac{dI}{dt},$$

where U is twice the coefficient of "self-induction;" for, that there is no induction on the permanent magnetizing current can be proved by putting a sensitive galvanometer in that circuit, no alteration being observed on closing or opening the secondary circuit. The above equation is similar to that given by Helmholtz for the induced currents at the closing and opening of a circuit, only that here E is a function of the time. This function could be determined as above, or as follows. The armature was moved by hand through each division of the period, and the current produced by that motion in the magnetic field measured by a reflecting galvanometer, and as the armature was started and stopped in each case, the coefficient of self-induction equalled zero, the curve being a sinusoid as stated above. By proper substitution the above equation can be integrated, and then, summed up for the half period, gives the equation for the mean intensity

$$I = \frac{\frac{2E}{\pi}}{\left(R^2 + \frac{4\pi^2 U^2}{T^2}\right)^{\frac{1}{2}}},$$

which is finally reduced to the empirical form by correction for the ratio between the mean values obtained by the galvanometric and electrometric methods. At the same time as the above experiments, the arc was examined optically, by a sort of phenakistoscope, as well as electrically, and the following facts obtained. At the moment when the current is nil, the potential between the carbon points is nil, but in an inappreciable time this difference amounts to 40 or 45 volts, which is maintained without alteration until the current again approaches zero. The final fall of the curve is very quick, but the details could be followed; not so with the commencement of the curve, which seemed to leap to its maximum value instantaneously. This difference of potential remains almost the same, not only for a current of the same mean intensity, but also when that is varied between very wide limits, as much, for instance, as two to one; the difference, however, diminishes as the current increases, the maximum variation being 4 or 5 volts.

The actual resistance of the arc is very small, the difference of potential between the carbons being due principally to the electromotive force of the arc, which may reach 30 volts; particles pass between the carbons as in an electrolyte, and if the arc is produced in a magnetic field subjected to the same periodic variations as the current, and normal to the plane of the carbons, the difference of the potential between them is increased in proportion to the strength of the magnetic field.

F. J.

Use of the Telephone in Measuring the Torsion of the Axles of Machines in Motion.

(Mittheilungen aus dem Gebiete des Seewesens, vol. viii., p. 433.)

The following is a description of an apparatus for measuring the torsion of shafts or axles in motion, invented by Sig. Rosio, of the Royal Italian Marine Academy. Two precisely similar brass wheels, of somewhat larger diameter than the shaft, are attached to the latter, at the greatest distance apart which circumstances will allow. Each of these wheels is provided with the same number of exactly similar and equally spaced vanes of soft iron. The wheels must be so placed that a plane passing through the axis of the shaft and the centre of a vane on one of the wheels, must also intersect the centre of a vane on the other wheel. Two precisely similar coils with steel cores, and of equal magnetic power, are placed at the same distances from the vanes of the wheels. The axes of the coils lie in a diametral plane of the shaft, and are consequently situated in a plane which cuts the wheels symmetrically. Each coil opposes the same pole to the vanes of the wheels. The wires of the coils belong to the same circuit in which the telephone is placed, but are wound in opposite directions on the two cores. Suppose, now, that the shaft is in motion, but undergoes no torsional strain, then any vane of one of the wheels will pass before a coil at the same instant as a corresponding vane of the other wheel, and consequently the induction currents in the coils will be of equal intensity but opposite in direction, and will neutralise each other. The telephone must consequently remain dumb, provided the two coils are really identical. When the axle, however, is put into a state of torsion, the corresponding vanes will no longer pass before the coils at the same instant; for in consequence of the torsional strain, the vanes will no longer be in the same diametral plane, but will lie in planes which make angles with each other proportional in size to the amount of the torsion. Consequently the induction currents will no longer neutralise each other, although they are opposite in direction, because they are not induced at the same instant, and the telephone will emit a more or less sharp tone, which will depend upon the number of vanes, the speed of revolution of the shaft, and the angle between

the corresponding vanes, *i.e.*, the amount of the torsion. If, however, the coil nearest to the driving machine be arranged in such a manner that it can be moved along the circumference of a fixed graduated circle, concentric with the shaft, but independent of the motion of the latter, at a certain instant the telephone will be quite silent, or else give out a note of minimum intensity. The angle through which the centre of the coil is displaced on the graduated circle at this moment shows the total torsion ϕ for the distance D between the two wheels; consequently the torsion per unit of length is $\alpha = \frac{\phi}{D}$. If the torsion has been also taken when the shaft is running, but doing no work, then the ratio of the power necessary to overcome friction to the total power transmitted by the shaft, will be represented by the fraction $\frac{\alpha'}{\alpha}$.

G. C. V. H.

On the Production and Reproduction of Sound by Light.

By ALEXANDER GRAHAM BELL, Ph.D.

(American Journal of Science, Oct. 1880, p. 305.)

Commencing with a short history of selenium, the Author describes the researches made by Mr. Sumner Tainter and himself, which resulted in the discovery that all substances when interposed in the path of a vibratory beam of light emit sounds, the pitch of which is dependent on the rate of vibration; and that in the case of selenium, the character of the light vibrations control the quality of the sound, and thus articulate speech can be reproduced.

Selenium, discovered by Berzelius in the year 1817, was determined by him to be a non-conductor; but Knox, in 1837, found that in a fused state it became a conductor; and Hittorf, in 1851, showed that in one of its allotropic forms it also conducted at ordinary temperatures. Selenium when rapidly cooled from a fused condition is of a dark brown colour, transparent in thin films, and a non-conductor, this being termed its "vitreous" state; if cooled with extreme slowness it appears of a dull lead colour, is opaque even in thin films, and is a conductor, this being termed its "metallic" or "crystalline" state. Later Willoughby Smith, in 1873, showed that the resistance of this "metallic" selenium decreased under the action of light, and others subsequently confirmed these results. Prof. W. G. Adams determined that the action was due to the yellowish green rays of the spectrum, and its intensity proportional to the square root of the illuminating power, and the same physicist, with Mr. R. E. Day, in continuing the researches, discovered that light produced in selenium an electromotive force without any battery. The most

sensitive variety of the metal was obtained by Dr. Werner Siemens[1] by continued heating for some hours at a temperature of 210° Centigrade, followed by extremely slow cooling; the conductivity of one specimen being fifteen times as great in the light as in the dark. Special means were introduced by him for lowering the resistance of the selenium cell, *e.g.*, two proximate spirals of platinum wire with the selenium interposed pressed between two mica plates. All these observations had been effected by use of the galvanometer, and it occurred to the Author that selenium in the circuit of a telephone and battery would give more marked results; and for this purpose the beam of light should be rendered intermittent, which could be done most simply by passing the light through holes cut in a revolving disk; and also that speech might be transmitted by actuating a perforated plate in connection with a diaphragm against which the voice was directed. Some selenium was obtained, but the resistance was found so high, and in fact, almost infinitely greater than that of any telephone constructed, that no audible effects could then be obtained. The Author felt, however, such confidence in obtaining successful results, that in a lecture before the Royal Institution in May 1878, he announced the possibility of hearing a shadow, which was further strengthened by Willoughby Smith's announcement that he had heard the action of light on selenium by listening to a telephone in its circuit. Towards the end of 1878 Mr. A. C. Brown communicated to him a method of reproducing articulate speech by the action of light on selenium placed in the circuit of a battery and telephone, which differed however from his, and of which more may be heard. The attention of the Author and Mr. Tainter was therefore first directed to reduce the resistance of the selenium cell, which had till then not been less than 250,000 ohms; and which was ultimately obtained, measuring as low as 300 ohms in the dark and 150 in the light. The best form of cell was constructed of a series of brass disks, insulated by similar ones of mica of a slightly smaller diameter, the alternate ones being in electrical connection; these being screwed up together on a common spindle, the resulting cylinder was heated above the melting point of selenium, and the metal then rubbed over the surface so as to fill the interstices, the superfluous metal was then turned off in the lathe, leaving bare the edges of the brass disks; very thin annular surfaces of selenium were thus obtained. Brass is used in preference to other metals for the electrodes, as the selenium seems to form an amalgam with it, and thus secures perfect contact. The first cells were rendered conducting by slow cooling in an oil-bath for a continuous period of forty to sixty hours' duration; but a method was afterwards discovered by which this could be effected in a few minutes. The selenium cell was heated over a gas-stove till the surface became dimmed, like the film of moisture produced by breathing on a mirror; this was continued until the whole

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lii., p. 400.

surface appeared granular or crystalline, when the heating was stopped and the cell cooled in any suitable manner. The best were obtained by not removing the heat until signs of melting appeared, when the melted portion immediately re-crystallized; this selenium was found, after cooling, to be a conductor and sensitive to light. If examined under the microscope, the cloudiness was found to be due to separate crystals on the suffface, having the appearance of leaden snow; in the crystalline state these crystals were arranged like basaltic columns, and as the temperature increased this structure disappeared, and that of a metallic pudding stone ensued. The selenium crystals produced by very slow cooling were completely different, presenting distinct facets. Having thus obtained a selenium cell suitable for the purpose, the apparatus for vibrating the beam of light was made in upwards of fifty different forms, the simplest being a diaphragm of a plane flexible mirror, such as silvered mica or microscope glass, against the back of which the voice was directed through a piece of flexible tubing; this mirror, under the action of the air vibrations, being alternately rendered convex and concave, thus dispersed and condensed the beam of light with corresponding frequency. The experiments were in general made with sunlight, a large beam being condensed on the diaphragm mirror after passing through an alum-water cell to eliminate the heat rays, and rendered parallel after reflection by another lens; this was received on the selenium cell placed in the focus of a parabolic reflector, with a battery and telephone in its circuit. Speech has by this means been accurately reproduced at a distance of 233 yards, the necessary privacy of the experiments limiting the trial of greater distances, though evidently such depends only on the practicability of throwing the beam of light on the required spot. The loudest effects have been obtained by interrupting the beam of light by what may be called the "optical siren," when a clear musical note could be heard, and if a screen were operated in front by a Morse key, signals could thus be readily transmitted. In experimenting on the nature of the rays to which selenium was sensitive, it was found that solutions of alum or bisulphide of carbon but very slightly diminished the intensity of the sound, whereas one of iodine in bisulphide of carbon cut off most but not all; even a sheet of ebonite did not entirely cause cessation of sound. Here, then, arose the fact that an invisible beam of light was able to convey the vibrations capable of affecting the selenium cell. Reasoning from the fact that the molecular disturbance of iron during the process of its magnetization can be heard by applying the ear to the iron itself, the Author concluded that the effect of light on selenium might also be perceived in the same way without a telephone and battery; this, however, had given no definite results, but on obtaining the anomalous results with the ebonite screen, listening to it was suggested and tried with most extraordinary success. It was therefore necessary only to arrange the ebonite as a diaphragm in the focus of the reflector

and the note could be distinctly heard when the vibratory beam was thrown upon it. On trying crystalline selenium in the same way, the sound was likewise reproduced, but more faintly; the following substances were also tried with equally successful results:—gold, silver, platinum, iron, steel, brass, copper, zinc, lead, antimony, german silver, Jenkin's metal, Babbitt's metal, ivory, celluloid, gutta percha, ebonite, vulcanised india-rubber, paper, parchment, wood, mica, glass and carbon. Ebonite gave the loudest tones except antimony and zinc; paper and mica the weakest. Thus the conclusion first stated was arrived at, that "sounds can be produced by the action of a variable light from substances of all kinds when in the form of thin diaphragms." The necessity of thin diaphragms is due to the circumstance that the molecular disturbance produced by the light is principally on the surface, and has to be then transmitted through the body of the substance. Sounds have also been heard by focussing the light in the interior of tubes formed of the substances above enumerated, which were ready at hand, and listening at the opposite end, and even by throwing the beam straight into the ear itself. The Author in conclusion acknowledges the encouragement he received from the kindness of those scientists who devoted themselves to experiments with the telephone, and trusts that the same favour may be extended to what he has named "The Photophone."

F. J.

The Electric Lift. By Dr. Werner Siemens.

(Electrotechnische Zeitschrift, 1880, p. 374.)

This is another application, by the firm of Siemens and Halske, of the transmission of power by the dynamo-electric machine. The use of hydraulic power hitherto employed is costly, owing to the tubes and apparatus requiring to stand a high water-pressure. The application of electrical transmission of power is, however, simple and cheap, both in its installation and subsequent working, especially if a motor is at hand for driving what may be termed the "primary" machine. The description, with drawings, is given of such a lift, erected in the grounds of the Exhibition at Mannheim, for raising visitors to the top of a look-out tower, a height of 20 mètres (65 feet). A rack, composed of steel plates joined by bars in the form of a ladder, was fixed perpendicularly between the ground and the top of the tower. This passed centrally through the cage, below which was fastened the "secondary" dynamo machine, which, by means of endless screw and worm, moved two pinions which geared into each side of the rack; thus moving the cage up and down according to the direction in which the dynamo machine rotated. A lever in the cage governed this direction, and in its central position threw the machine out of

circuit, thus stopping the motion. Four rollers above and below acted both as guides to the cage and as electrical connections between the rack, which formed one of the conductors, and the machine, the other conductor being supplied by the metal band ropes, which, passing over pullies fastened to the tower, were connected at one end to the cage, and at the other to a balance weight. More than 8,000 persons were conveyed, while the Exhibition lasted, without any accident, the speed being about half a mètre (20 inches) per second.

For the lifting of goods, &c., where safety is not the first requirement, the machine might be fixed and ropes used, as in building construction or other such works.

F. J.

On a Simple Method of Identifying a Submerged Telegraph Cable without Cutting it. By W. P. JOHNSTON.

(Proceedings of the Asiatic Society of Bengal, 1880, p. 92.)

This Paper describes a method of identifying a submerged cable, as, for instance, when one of two similar cables laid across a river has become faulty. The Author uses for this purpose a telephone, which is the most sensitive instrument at present available for indicating small currents acting for very short intervals. Orders having been given that signals are to be sent only through the good cable, a telephone is attached to the wire-guards of the raised cable, the distance between the two connecting points being not necessarily greater than 6 feet. If the line to which the telephone is attached is uninjured, every signal sent through the cable can be distinctly read. If no signals can be heard in the telephone, then it is the faulty cable which has been grappled. The reverse way may also be chosen by connecting a telephone to the conductor of the cable on shore, and sending signals from a battery on the boat, through the wire-guards; in this manner the telegraph engineer on the boat can communicate with the shore.

After the Paper was read, Mr. Louis Schwendler, M. Inst. C.E., illustrated this method of applying the telephone to practical purposes, and two members of the Government Telegraph Department communicated with each other in the manner above described.

F. G. D.

Study on Gunpowder. The Wetteren Powder. By E. FARRET.

(Revue Maritime et Coloniale, vol. lxv., p. 519.)

The Author enters at some length into the requirements of a good gunpowder, and examines into the qualities of all the existing systems of manufacture. The principal object sought for in a

good gunpowder is the power of keeping a uniform pressure of gas on the base of a projectile. This can only be attained if the powder emits larger quantities of gas during each succeeding interval of time as the combustion progresses. According to the Author the combustion of powder does not take place uniformly, but increases in rapidity as the pressure increases, and hence to obtain a so-called progressive powder, it is only necessary to form it into hard homogeneous cakes of uniform thickness, which will neither break up nor lose their shape during the progress of the combustion.

In the French guns of the 1870 pattern homogeneous large-grained powders are used. They are of two sorts, viz., those made at Wetteren, and at the French factories of Bouchet and Sévran-Livry. The Wetteren powder consists of saltpetre 75 parts, sulphur 12, and charcoal 13. Its gravimetric density is 1·0813. The speed of combustion under the normal pressure is $W = 0·10$. There are 370 grains in the kilogram. The shape of each grain is approximately spherical. During fabrication the powder goes through the following processes: 1st. The formation of binary mixtures and the trituration of each of these mixtures in iron barrels, containing each one hundred bronze balls. 2nd. The ternary mixture, which takes place in leather barrels containing fifty wooden balls. The ternary mixture is then watered, divided into portions of 25 kilograms each, and put into casks. 3rd. Grinding in the mills. 4th. The cake is cut up, and the dust and grains mixed and carried to the hydraulic presses. 5th. The cake is submitted to a hydraulic pressure of 97 kilograms per square centimètre (1,380 lbs. per square inch). The usual charge for a press is forty-five layers of cake, weighing together 330 lbs. 6th. The pressed cake is cut up into grains by machinery, and those grains which are too large or too small are separated. 7th. The first glazing. The powder is first damped, and according to the more or less angular appearance of the grains, a greater or lesser quantity of the ternary mixture is added. The powder is then put into barrels 7 feet 2 inches long, and 2 feet in diameter. Each barrel is divided into three compartments. Each compartment receives a charge of at least 121 lbs. 8th. The drying, which lasts three days. The temperature must not exceed 122° Fahrenheit. 9th. The second glazing, which takes place in barrels 6 feet 10 inches long, 2 feet 2½ inches in diameter, and lasts three hours. 10th. Classification of the grains by means of zinc sieves. Wetteren gunpowder costs 1 franc 80 centimes per kilogram (7·8*d.* per lb.) delivered at the Turcoing station.

Since the introduction of the Wetteren powder, the French manufacturers have endeavoured to make a powder which should compete with and even surpass it. Since 1867 experiments in this direction have been made at the powder factory at Bouchet. The Bouchet powder consists of saltpetre 75 parts, sulphur 10, charcoal 15, which is nearly the same composition as the English, Russian, Swedish, and American powders. The results obtained

with this powder are satisfactory. At Sévran-Livry powders are manufactured very similar to those of Bouchet. Both these powders are made in accordance with the ideas propounded in the work of Captain Castan. The density of the cake is very great, and it is cut into parallelopipedons, the sides of the bases of which are on the average one and a half times the thickness of the cake. A greater length would render the powder more progressive, but would expose the grains to the risk of breakage under transport.

G. C. V. H.

Cause of the Explosion at the Royal Powder Mills at Wetteren.

(Official Report by Prof. J. CHANDELON.)

In a detailed report on the cause of the destructive explosion in May 1880 at the Royal Powder Mills at Wetteren, Professor Chandelon traces the disaster to its source, and comments on the circumstances attending it. The unusually destructive effects of this accident were mainly due to the faulty arrangements adopted at these works. A series of explosions in different buildings followed the initial detonation, a consequence of the buildings being in too close proximity one to another. This disposition of the buildings was adopted many years ago, before the use of teledynamic cables allowed of their wide separation. In more modern works, the motive power is transmitted to the mills from considerable distances by this means. At the powder mills at Ockh'ta in Russia the distance exceeds 1,500 yards. The Author, in his report, recommends the complete isolation of the dangerous buildings by surrounding each with earth parapets, the entrance through which should be defended by a mound or mantlet, and the transmission of power to the mills in all cases by means of teledynamic cables. The initial explosion at Wetteren was caused by two of the workmen, whose duty it was to remove the dried powder from the drying-house, dragging along the floor the vessel containing about a hundred and fifty pounds of powder, which they ought to have carried between them. The friction of this heavy weight upon the floor inflamed some of the loose grains lying about. The Author warns manufacturers to provide against this source of accident, which, he states, he has on a previous occasion observed to have caused an explosion.

G. G. A.

Charges of Dynamite in Rock Blasting.

By Major J. L. L. MORANT, R.E., Assoc. Inst. C.E.

(Professional Papers on Indian Engineering, 1880, pp. 302–307.)

In a long Paper on the use of dynamite in rock blasting, the Author takes occasion to dispute the old rule by which the charge

of explosive is made to vary as the cube of the line of least resistance. In the numerous experiments which he undertook to test the action of dynamite, and which are described in detail, he found that the rule did not hold good. The fact was proved in the following manner. He took a certain line of least resistance, say, for example, one of 3 feet, and loaded numerous corresponding bore-holes with various charges until one was found which was as nearly as possible exactly sufficient. With the coefficient on the cube of the line of least resistance thus obtained, he calculated other charges for holes with lines of resistance both less and greater than 3 feet. In these cases it was always found that when the lines of resistance were less than 3 feet the charges were too small, while when the lines of resistance were greater than 3 feet the charges were too large. Hence the Author infers that the explosive charges, or which amounts to the same thing, the resistances to the charges, do not vary as the cube of the line of least resistance. He further maintains that the square of that line should be taken into account in determining a charge, since the square surfaces of the rock from which the mass is torn affect the result much more than the mass itself. In a case, for example, in which the rock to be blasted has two clear faces, the explosive has first to fracture the rock along three faces, and then to push along the mass dislodged against the friction of this mass upon the bottom face. From a consideration of these facts, it becomes clearly apparent that in small blasts, the area offers the greatest proportionate resistance, while in large blasts the preponderating resistance is due to the mass. That the area may the most affect one problem, while the cubic contents may the most affect another, is seen in the following case. A boulder quite free at the bottom and having a vertical bore-hole down its centre, can resist fracture only by the cohesion of its particles; here the explosive charge must vary as the area, or the square of the line of least resistance. But if the bore-hole were drilled horizontally with the boulder the charge might be more affected by the weight than by the area, and if the mass were very large, the resistance due to the weight, that is, the resistance shown by the cube of the line of least resistance, would greatly preponderate. To take these conditions into account, the Author establishes the formula for charges of dynamite:

$$W = AL^2 + BL^3;$$

in which W represents the weight of the explosive in ounces avoirdupois, L the line of least resistance, and A and B coefficients to be determined by experiment for each kind of rock. For gneiss rock, and the common case of only one clear face, the Author found $A = \frac{5}{12}$ and $B = \frac{1}{6}$. When the footings of rock required the bore-holes to be carried down below the bottom of the face, A became = 1; and in the case of two clear faces, B became $\frac{1}{3}$. The following

useful Table, based upon the conditions of the first case, is given:—

Line of least Resistance in Feet.	Charge of Explosive in Ounces.	Number of Cartridges 8 to the lb. (1 Cartridge = 2 ozs.)	Number of Cartridges 7 to the lb. (1 Cartridge = 2½ ozs.)
1	⅔	1 primer.	1 primer.
1½	1½	2 primers.	2 primers.
2	3	1 cartridge + 1 primer.	1 cartridge + 1 primer.
2½	5⅓	3 cartridges + 1 „	2 cartridges + 1 „
3	8⅓	4 „ + 1 „	3 „ + 1 „
3½	12⅔	6 „ + 1 „	5 „ + 1 „
4	17½	9 „ + 1 „	8 „ + 1 „
4½	23⅔	12 „ + 1 „	10 „ + 1 „
5	31⅓	16 „ + 1 „	14 „ + 1 „
5½	40⅓	20 „ + 1 „	17 „ + 1 „
6	51	25 „ + 1 „	22 „ + 1 „
6½	63½	32 „ + 1 „	28 „ + 1 „
7	78	39 „ + 1 „	34 „ + 1 „
7½	94	47 „ + 1 „	40 „ + 1 „
8	112	56 „ + 1 „	48 „ + 1 „
8½	133	67 „ + 1 „	57 „ + 1 „
9	156	78 „ + 1 „	67 „ + 1 „

The following Table, which will also be found very useful for reference in practice, is added:—

Diameter of Bore-hole.	Dynamite in one linear inch of Bore-hole.	Dynamite in one foot of Bore-hole.	
Inches.	Ozs.	Lbs.	Ozs.
1	0·670	0	8·040
1½	1·507	1	2·084
2	2 682	2	0·184
2½	4·189	3	2·286
3	6 032	4	8·384

G. G. A.

The Raising of the Steam-Launch "Neptun."

(Die Eisenbahn, vol. xiii., p. 96.)

On the 25th of July 1880 the steam-launch "Neptun," plying on Lake Biel, Switzerland, was careened by a furious gust of wind, and sank in deep water, drowning all the passengers but two. A committee was at once formed to recover the bodies, and, if possible, to raise the boat; but, owing to the unfavourable conditions for dragging, it was some time before the exact position of the sunken vessel could be determined. The boat, which was 33 feet long and 6½ feet beam, was ultimately found in the neighbourhood of Tüscherz, about 2½ miles from Biel, lying in 75 mètres (246 feet) depth of water.

Inquiries abroad elicited the opinion that 45 mètres was the limit up to which operations of the nature proposed were feasible, and that 75 mètres was quite exceptional for such work. Nevertheless, it was resolved to make the attempt, and an estimate was invited from a French firm, who required 10,000 francs (£400). This determined the committee to invite proposals from local parties. Several schemes were presented, some good, some bad. One proposed to screw together a length of 75 mètres of gas pipe, which was to be driven into the boat, and the latter pulled up. Another suggested the use of four fluked grapnels, to drag the boat into shallow water. The most promising suggestion proceeded from Herr Favre, of Neuveville, who accompanied his proposal by a model, which worked with great ease and accuracy. In the result, Herr Favre's scheme was adopted, and the firm of Chappuis & Co. of Nidau, was instructed to make the necessary apparatus. This consisted simply of a double pair of gigantic tongs, connected together, and opening to the extent of 6 mètres (about 20 feet). Each arm of the tongs was formed of a lattice girder, about 30 feet long, shaped like a fish-hook without the barb. The two pairs of tongs were hinged on a bar of iron common to both, by which arrangement the one pair of tongs was kept parallel with the other, the distance between them being about 8 feet. By hauling on chains attached to the arms where the span was widest, the tongs could be opened to their full extent, and similar chains attached to the upper extremities of the arms acted to close them. The weight of the tongs was 1,453 kilograms (about 29 cwt.) On the evening of the 25th of August, one month after the accident, this apparatus was completed and installed on a platform supported by two pontoons moored over the sunken vessel. The latter having been grappled, the capstans were manned, and the boat, weighing 3 tons, slowly raised to the surface. Shortly after 11 o'clock at night the vessel was again afloat, uninjured, except that the blades of the screw were knocked off and the cabin windows were broken. The bodies of the passengers were found in the cabin. The whole cost of the operations, including dragging for the boat, was barely 3,000 francs, or less than one-third of the amount of the estimate obtained from Paris.

F. G. D.

The Reese Fusing Disk.

(American Engineer, vol. i., p. 178.)

Mr. Jacob Reese, of Pittsburg, has succeeded in cutting iron and steel by revolving near it, at a high speed, a thin metallic disk. The disk is of wrought iron or soft steel, 42 inches in diameter and barely $\frac{3}{16}$ inch thick. It runs at a speed of 25,000 feet per minute at the periphery, when a groove is instantly melted in a

round bar of steel held before the disk, and the metal it contained drops down in a fused state. When the disk is properly mounted so that it has no lateral movement, the ends of the bar are left smooth and level. In practice the bar is placed in a chuck and rotated at two hundred revolutions a minute in the same direction as the disk. The instant the bar is brought near, a channel slightly wider than the thickness of the disk ($\frac{5}{16}$ inch for a $\frac{3}{16}$ disk) is fused, which deepens regularly as the bar is fed forward until the latter is severed. A 2-inch round bar of steel has been fused through in ten seconds, and a $1\frac{5}{8}$-inch bar in seven seconds. If the disk be stopped before the bar is severed it is found not to touch the bar at the periphery, thus showing that its action is different from that of the "cold saw" used for cutting rails. Mr. Reese attributes the fusing to the impact of the particles of air hurled with great velocity against the objects presented to the periphery of the disk. It has been principally used for cutting off shafting, gun-barrels, &c., which are made smooth and ready for centering or boring without any further dressing being required.

F. G. D.

Armoured Turrets for the Defence of the German Coasts.

(Mittheilungen aus dem Gebiete des Seewesens, vol. viii., p. 547.)

The turrets which are to be built during the current and the coming year for the defence of the upper Prussian coasts will be protected with chilled cast-iron plates, with the exception only of the roof plates, for the experiments at Meppen in August 1879 have proved that chilled cast iron is superior to rolled iron for the protection of coast defences. The turrets will consist of three principal parts, viz., the cupola, the armour, and the foundations. The cupola will be constructed of segments having an average thickness of 500 millimètres (20 inches); the armour will also be constructed in segments, and will protect the walls of the casemate, or chamber, which contains the gun. Masonry foundations will support the wrought-iron underworks of the turret proper. The armament will consist of a 15-centimètre (6-inch) steel gun for each tower, except in a few special cases, where two such guns will be employed.

In the cases of turrets destined to protect the mouths and fords of rivers, the guns will be withdrawn from the rear when it is necessary to change or to repair them. In other cases the foundations will be so arranged that the guns can be withdrawn from underneath the turrets. The muzzles of the guns will only project 300 millimètres (12 inches) through the embrasures, as this distance has been found sufficient to protect the gunners from the concussion due to the explosion. The turrets will be made to

revolve by hand, so quickly that an enemy will not be able to take aim at the embrasures. The turrets are to be made in the chilled cast-iron factory of Herr Gruson at Magdeburg.

G. C. V. H.

On the Introduction of the Metric System into Machine Shops in America. By C. Sellers.

(Journal of the Franklin Institute, November 1880, p. 289.)

The French metric system was legalised in the United States of America in 1866. In trade, it matters little what system of measures is adopted. The machinist, on the contrary, must possess costly means of measuring and weighing, to a degree of exactness unknown to others, and the result of the measurements and weights so ascertained are fixed and unalterable. Mr. Sellers is opposed to compulsory legislation, because "the metric system is not well adapted to the practice of the machine-shop." The value of the unit of measurement is all important in the first production of machines. In shop practice and in mercantile practice, to obviate endless variety and confusion, certain dimensions in progressive order are adopted, being the sizes most useful and most saleable; and it is by the use of well-considered ranges of shop sizes and merchant sizes, easily remembered, that the maximum of convenience is obtained at the minimum of cost.

The French mètre cannot be the unit of measurement, since much the greater number of sizes used in the construction of machines are less than a mètre. Hence the millimètre is practically the unit; and by its use only decimals are avoided. With this unit is compared the unit of one inch—the standard unit in the States. In the drawing office, the metrical scales descend from full size to $\frac{1}{2}$, $\frac{1}{5}$, $\frac{1}{10}$, $\frac{1}{20}$, $\frac{1}{25}$, $\frac{1}{50}$. Here the intervals are irregular: there is a jump from $\frac{1}{2}$ to $\frac{1}{5}$, and again from $\frac{1}{25}$ to $\frac{1}{50}$. But the scales that may be obtained from an ordinary inch-rule, descend from full size to $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{6}$, $\frac{1}{8}$, $\frac{1}{12}$, $\frac{1}{16}$, $\frac{1}{24}$, $\frac{1}{32}$, $\frac{1}{48}$, $\frac{1}{64}$, making twelve scales in all, as compared with seven decimal scales. The Author, who had had long experience of the metric system in his workshops for the manufacture of injectors, "hoped for gain in the drawing-room from the use of metric scales; he expected to find more than in the machine-shop; he has been disappointed in both."

In the machine-shop, a case of good systems *versus* bad systems, is referred to—the system of drills. A series, advancing by $\frac{1}{16}$ inch up to 1 inch, and by $\frac{1}{8}$ inch up to 2 inches, is equivalent to an advance by $1\frac{1}{2}$ millimètre in a metric system. Such an advance as $1\frac{1}{2}$ millimètre is impracticable, because it must be "memorised" entire; it affords no holding-place for the memory. The German house of Heilmann, Ducommunn, and Steinlen, at Muhlhausen, make twist drills from 10 millimètres to 50 millimètres, advancing

by 1 millimètre; but the sizes in use in their own shop are, 10, 12, 15, 18, 20, 23, 25, 28, 30, 32, 35, 37, 40, 42, 45, 47, 50. Here is a series which must be "memorised" entire, as its rate of advance is not by two, or by three either, in regular sequence. Other cases of practical difficulties are instanced by the Author, and he concludes that it is unwise to tamper with the existing metrology of their workshops in America, for which large capitals have been invested, and that it is better to continue to amend what they have, to promote uniformity.

D. K. C.

Telescope for Pointing Long Range Guns. By P. DE BROCA.

(Comptes rendus de l'Académie des Sciences, vol. xci., p. 527.)

This invention, which was designed as a complement of the Author's double fore-sight for land artillery, is based upon a particular arrangement of the telescopes in common use, whereby a distant object to be fired at may be seen at the same time as others which are very near the eye, such as the sights of the gun and the object-glass of the instrument itself. By means of the apparatus a gun may be accurately sighted upon the object aimed at, in the same way that a gun is laid by the eye at short range; and this may be done without mechanism or special contrivances for keeping the optical axis in exact relation with the different sighting lines of the guns. The telescope is put into position by hand either by resting its object-glass end against the back-sight of the gun, or, which is a more convenient way, by placing it upon a rest near the breech of the gun. The practical value of the invention lies in the fact that the gunner is enabled by means of it to see at the same time the object-glass of the telescope, the back- and the fore-sight of the gun, and the distant objects upon which the gun is being laid.

The simultaneous view of near and distant objects is obtained by the employment of an achromatic semi-convex lens, cut exactly through its centre, which is interposed upon the path of the rays of light, either between the object-glass and the fourth eye-piece, or in front of the field lens of a Campani compound eye-piece. This half-lens, which is made adjustable to give a clear view of the object-piece, must be of short focus (from 1 to 1·2 inch for ordinary telescopes), so that its combination with the set of eye-pieces may not produce magnified images of near objects, a circumstance which would render the fore-sight indistinctly visible. The object-glass of the telescope has its centre determined by the apex of a small black paper triangle glued upon its flat face, and by the apex of this triangle the sight is directed. It is to be remembered that in this new instrument the optical axis being determined on one side by the small aperture to which the eye is applied, and on the other

by the centre of the object-piece, the diaphragm, which is situate in the focus of the eye-glass of a Campani compound eye-piece, must have one of its halves covered, except at the centre, where a small semicircular groove is left through which the images of near objects given by the objective half-lens are seen. This groove limits the view of the object-piece by hiding the interior of the instrument from the eye. Distant objects are seen through the uncovered portion of the diaphragm and the centre of the object-piece, the back-sight and the double fore-sight of the gun through the groove. Contact of the images of these different objects takes place in the middle of the diameter of the diaphragm. As the objective half-lens is independently mounted, this glass, as well as the half-covered diaphragm, may be removed, and the telescope then becomes one of an ordinary character. Thus any well-centred telescope may be transformed, at a trifling cost, into an instrument for laying guns.

G. G. A.

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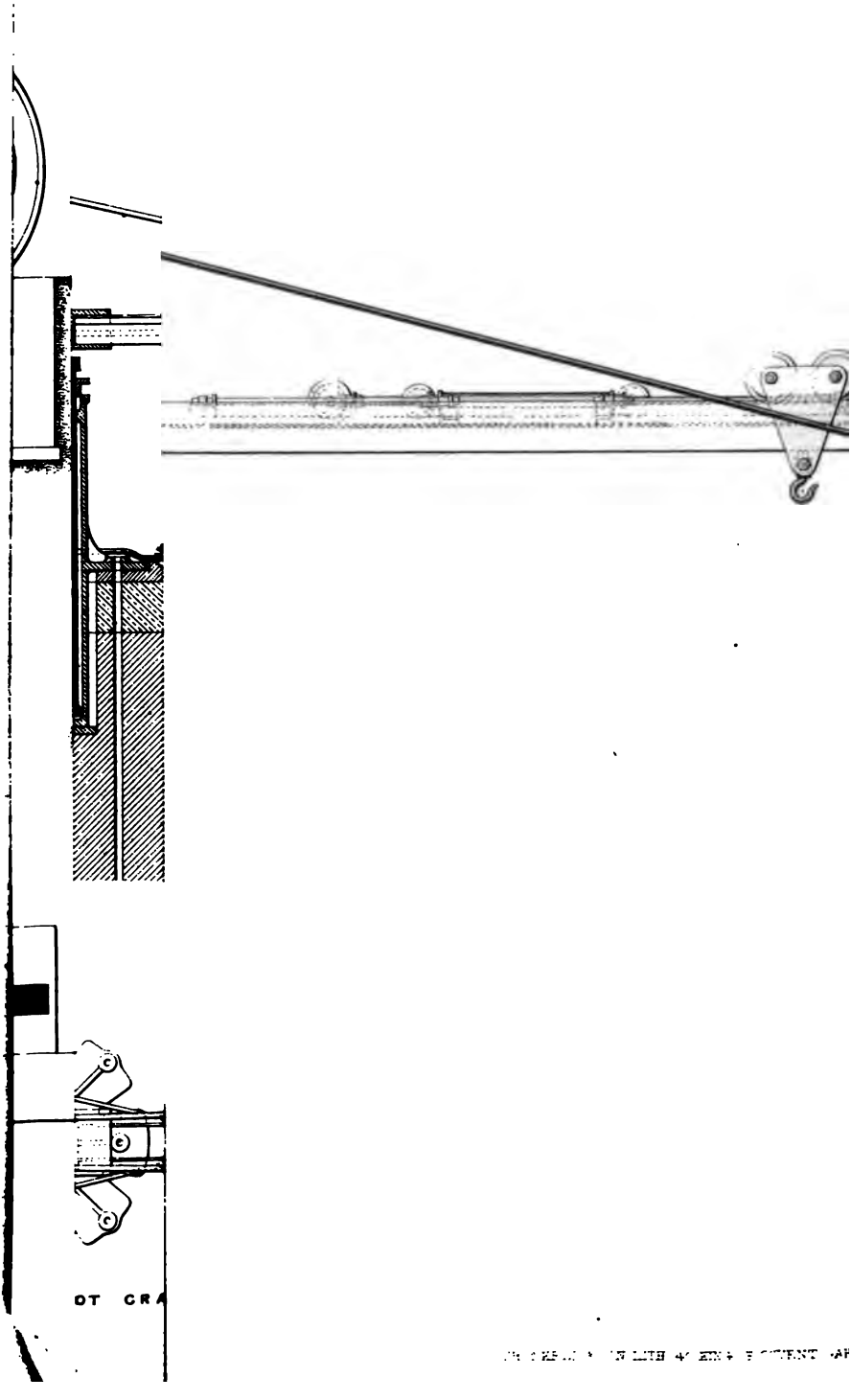

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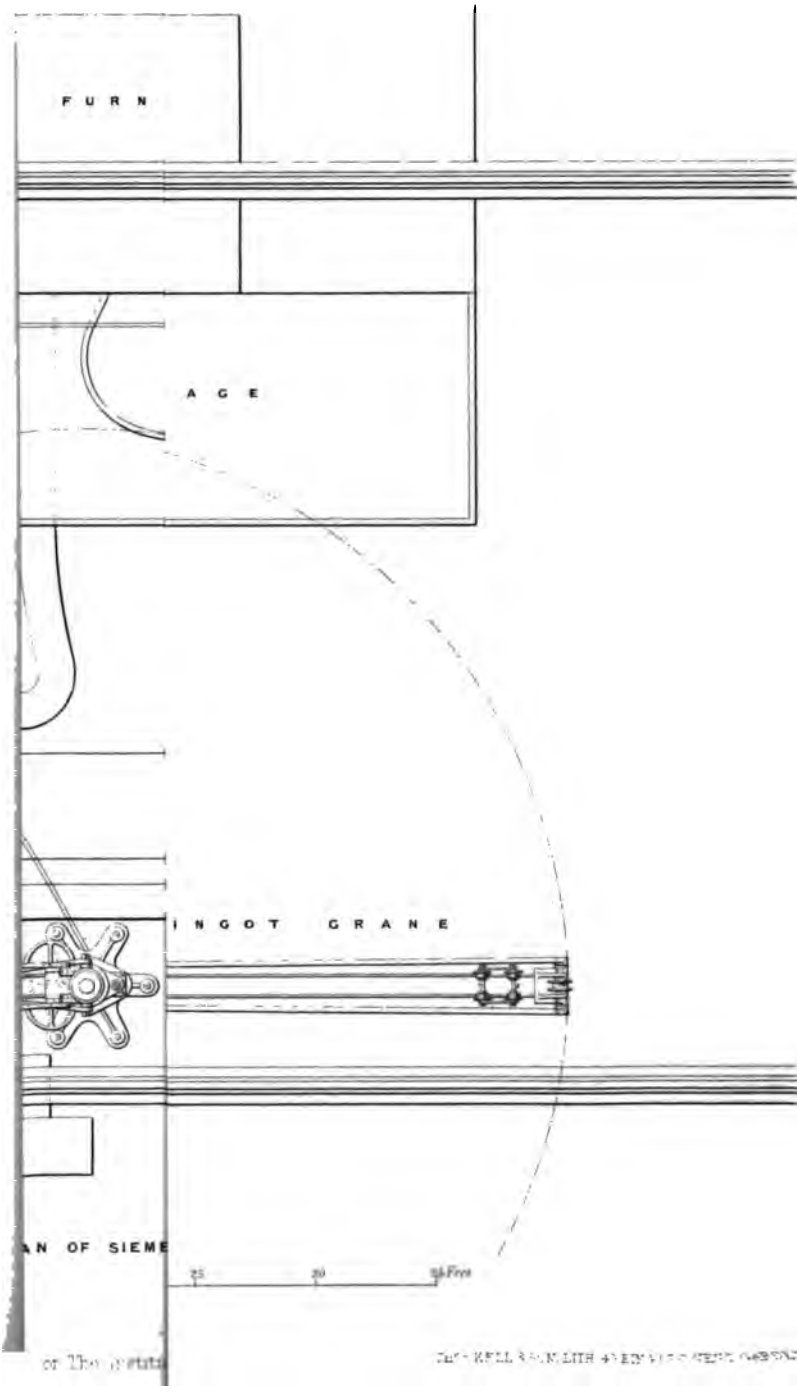

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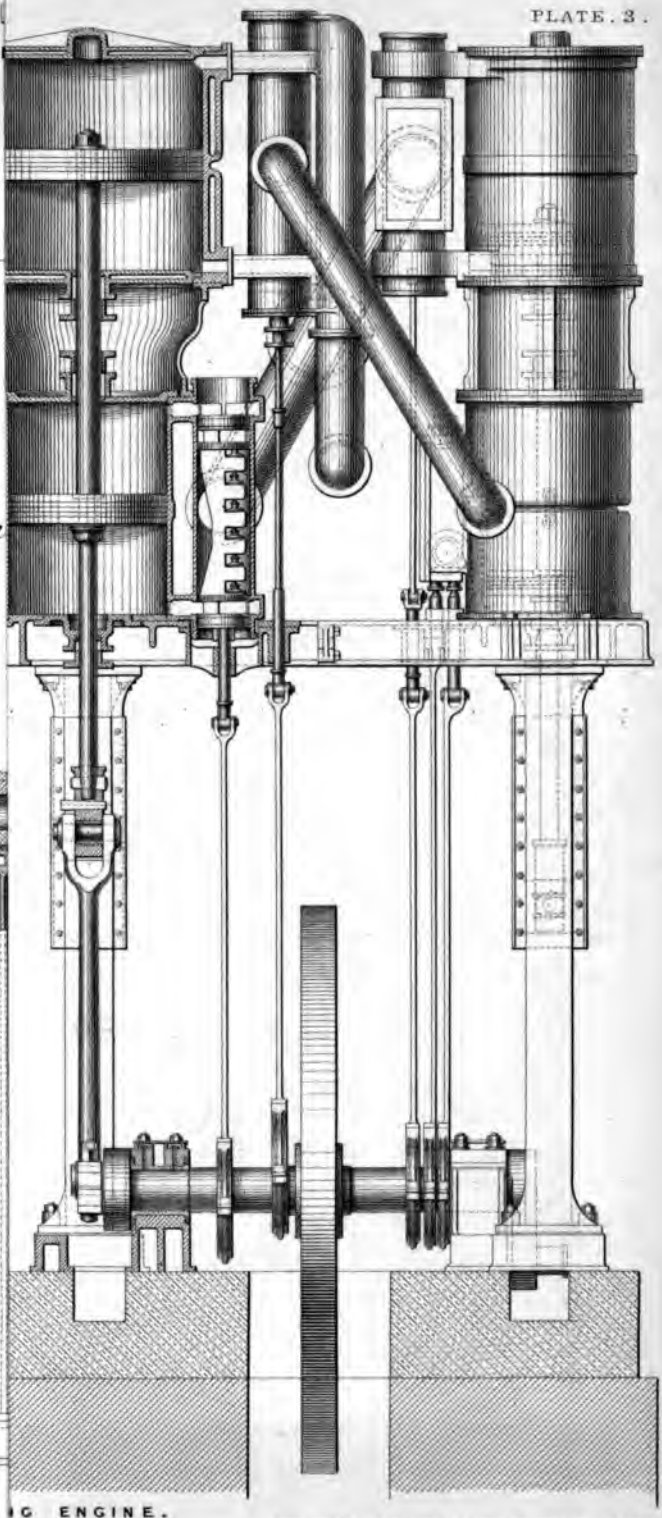

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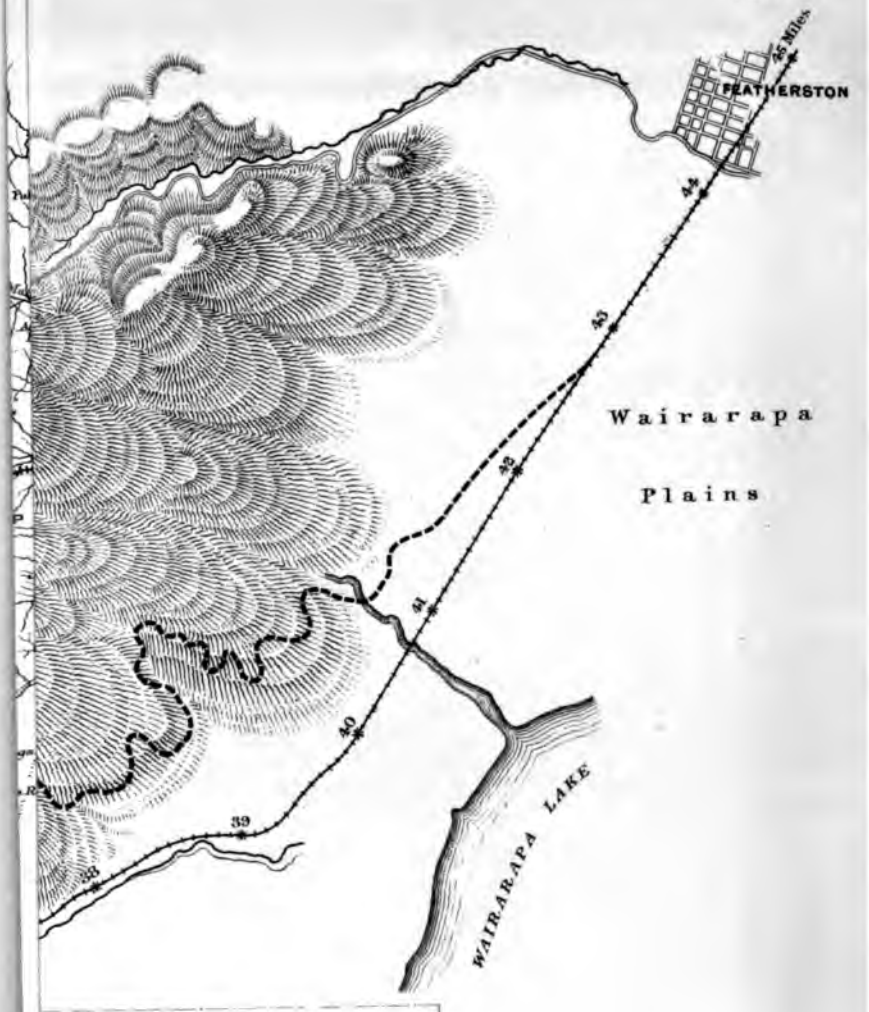
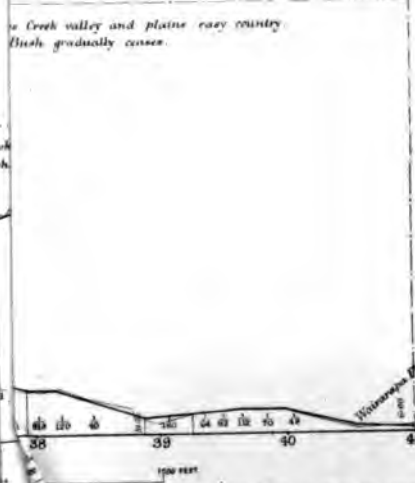
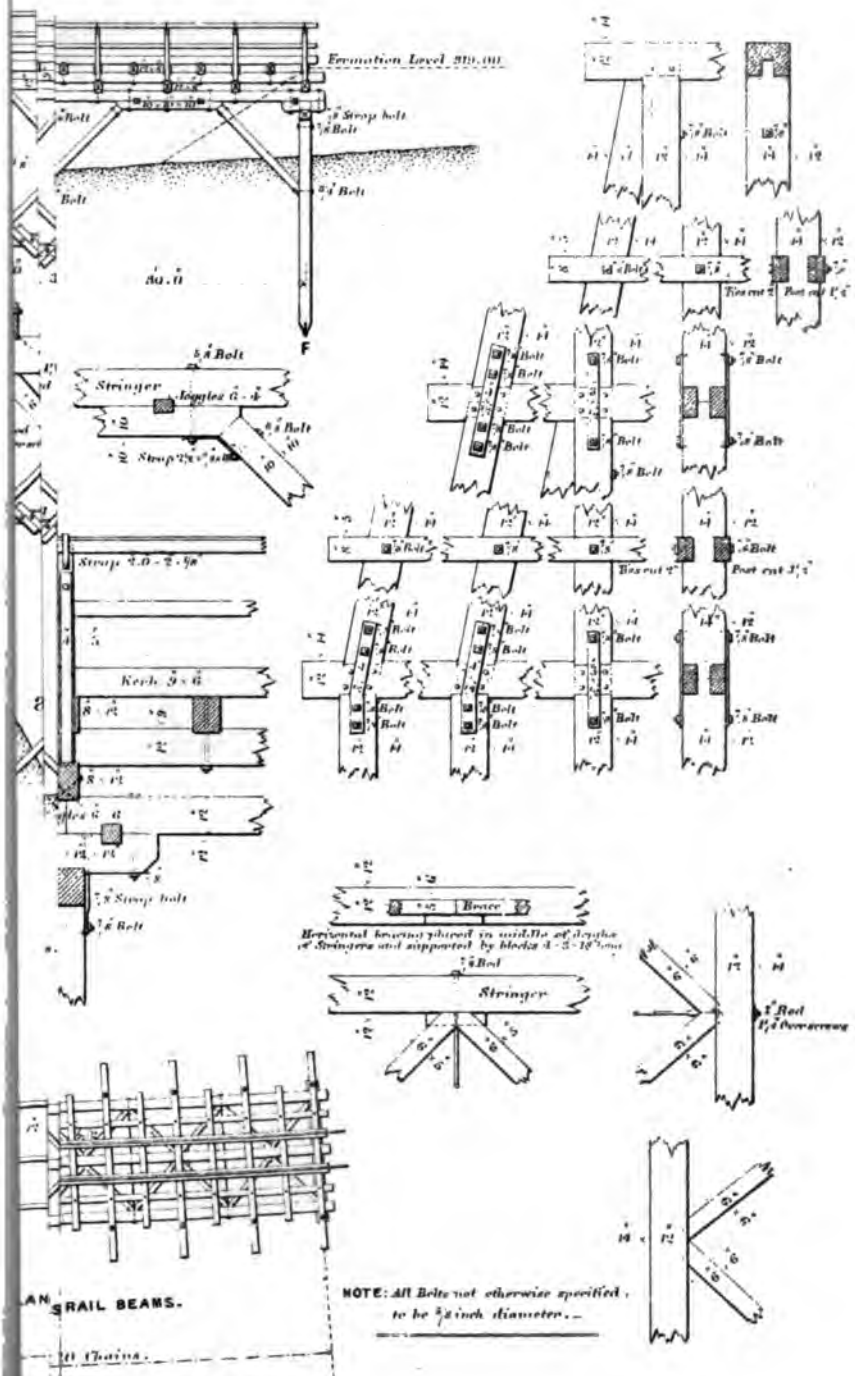
PLATE. 4.





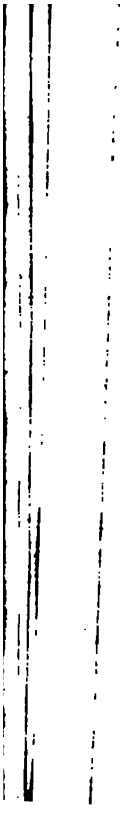
THOS KELLY & SON, LITH. 40 KING ST. COVENT GARDEN.

PLATE. 5.



RAIL BEAMS.

THOS. KELLAWAY, LITH. 40 KING ST. COVENT. GARDEN



CEYLON

PLATE 6

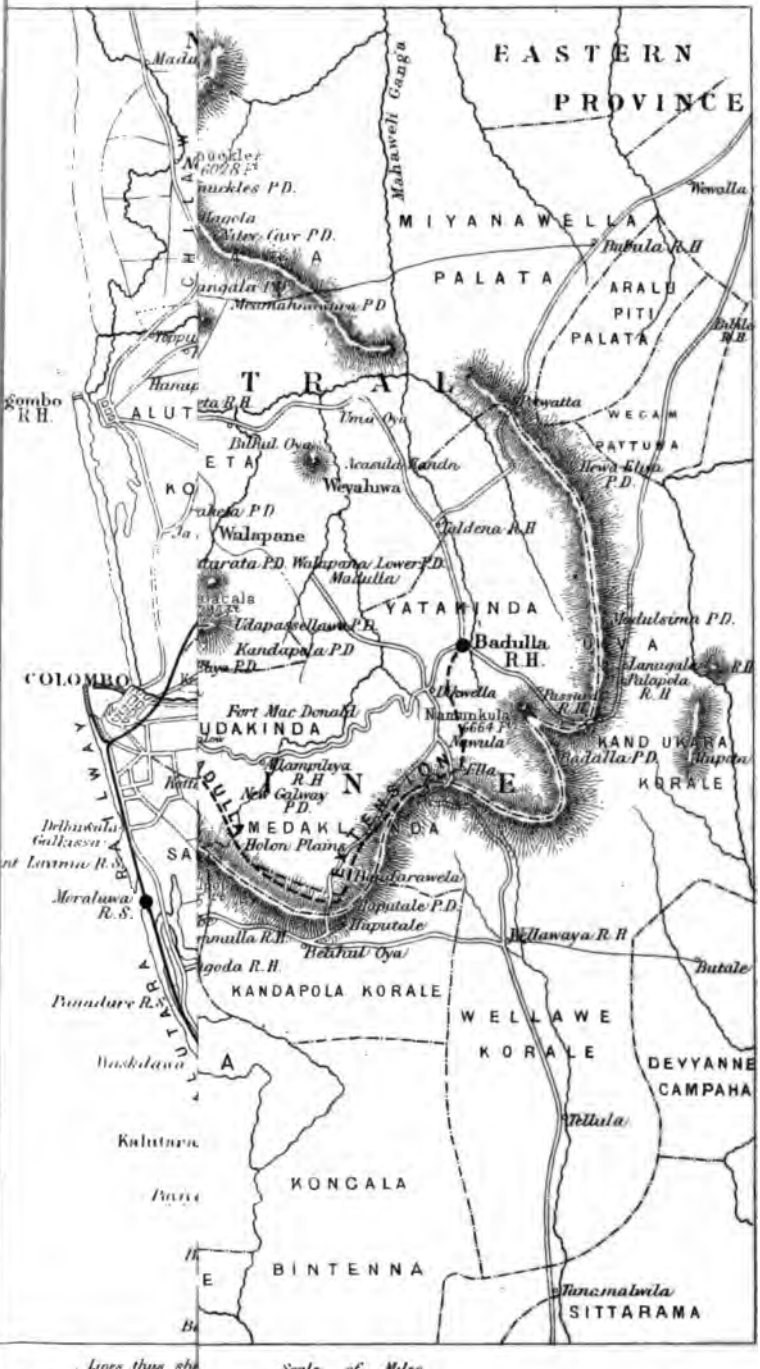
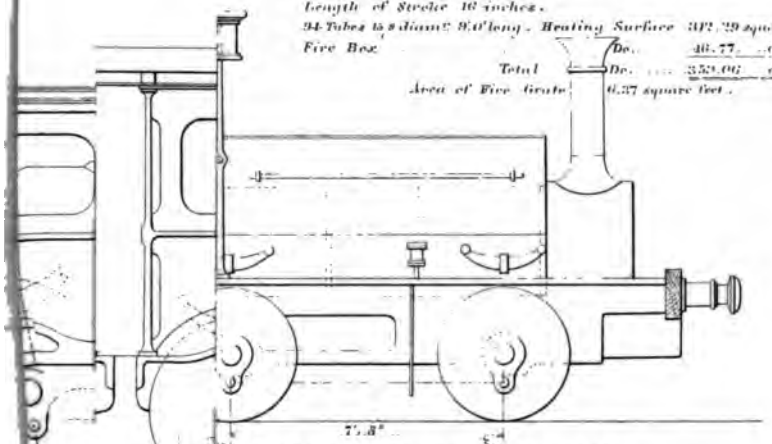


PLATE. 7.

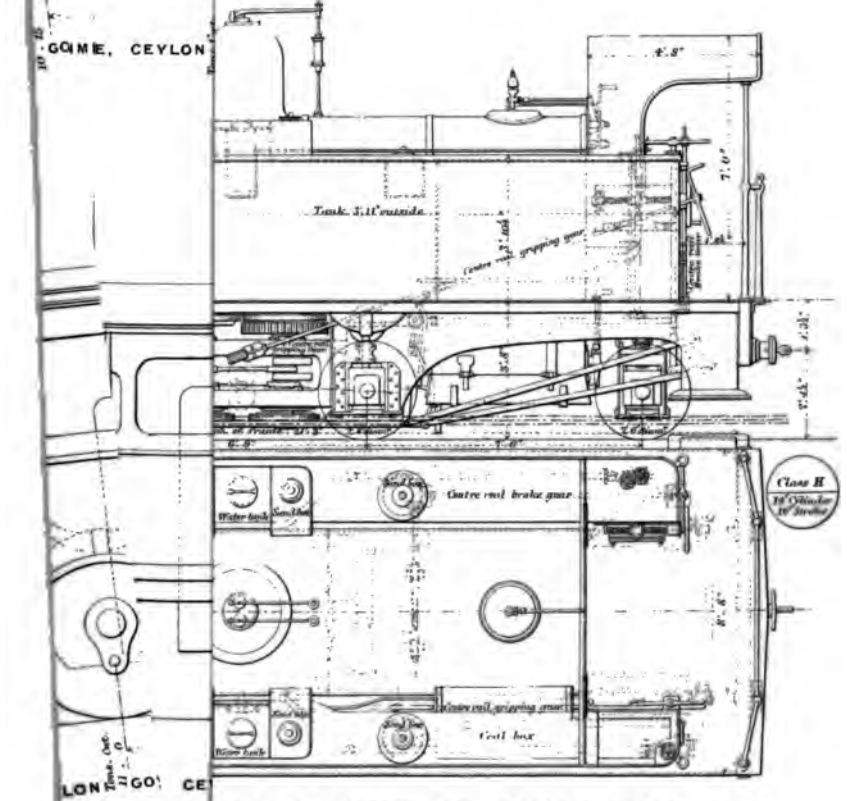
...YS.

Diameter of Driving Wheel 3 feet 6 inches.
Diameter of Cylinder 10 inches.
Length of Stroke 16 inches.
94 Tubes 1¾ diam^r 9'.0" long. Heating Surface 317.29 square feet.
Fire Box ... *Do.* ... *46.77* ... *do.*
Total ... *Do.* ... *353.06* ... *do.*
Area of Fire Grate ... *6.37 square feet.*



CEVLON GOVERNMENT RAILWAYS.

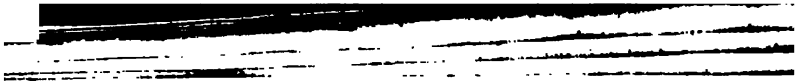
...GOME, CEYLON



...LON... GO... CE...

...NTRAL RAIL SYSTEM, NEW ZEALAND RAILWAYS.

...E & ... PLATE ... KING ... STREET GARDENS.



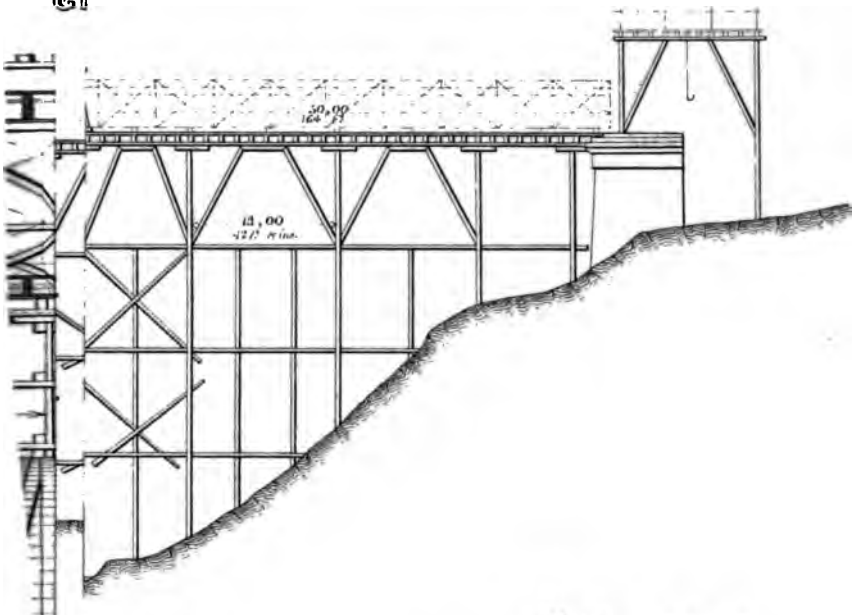
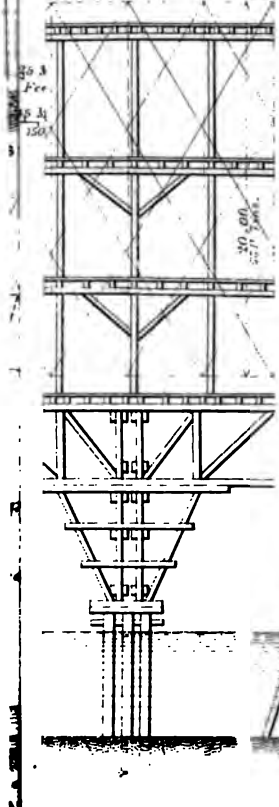
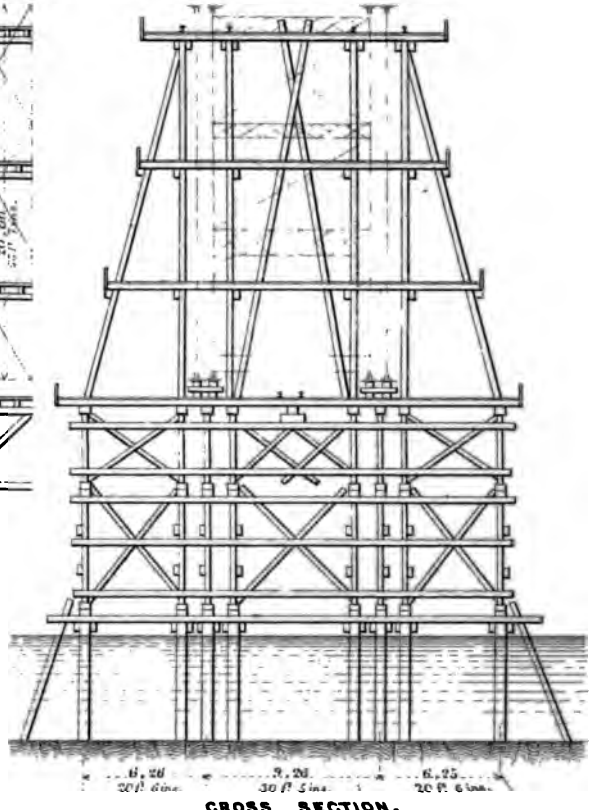


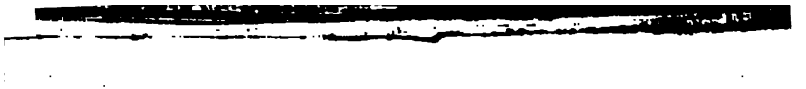
Fig: 4. Scale $\frac{1}{400}$th



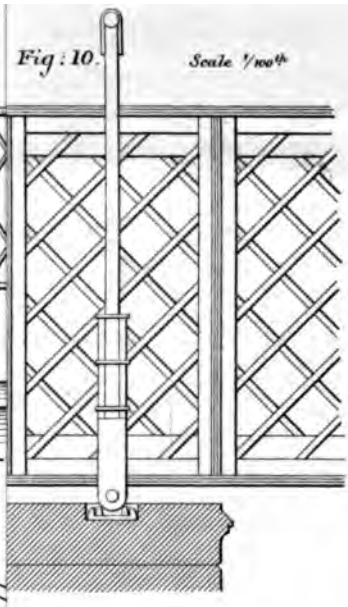


CROSS SECTION.

THOS. BELL & SON, LITH. 44, KING ST. COVENT GARDEN

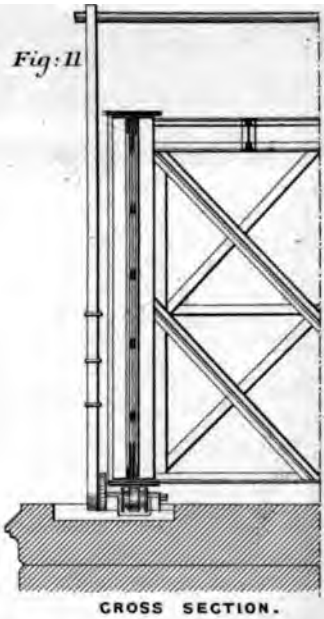


7. Fig: 10. Scale 1/100th



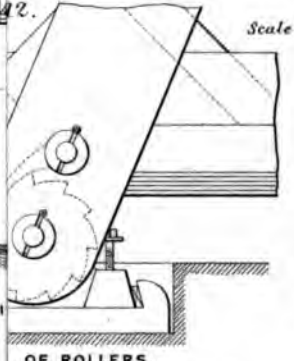
HOL

Fig: 11



CROSS SECTION.

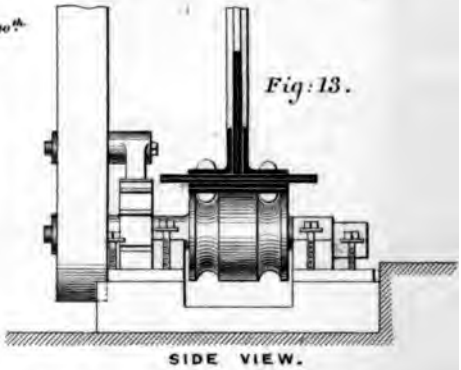
12. Scale 1/30th



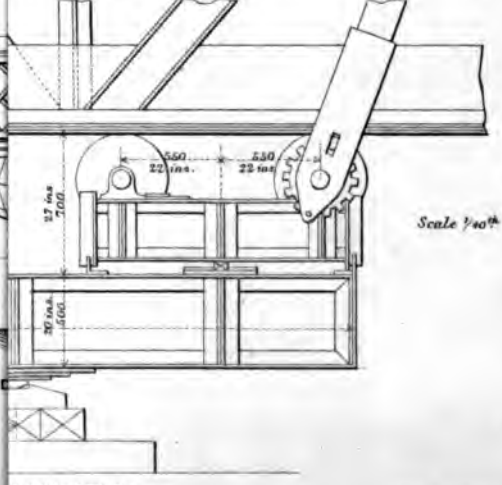
BRI

OF ROLLERS.

Fig: 13.



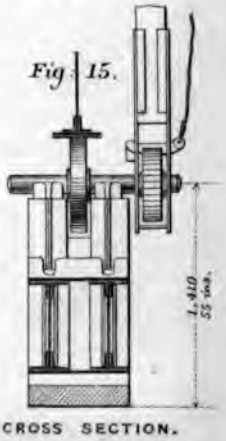
SIDE VIEW.



BRI

Scale 1/30th

Fig: 15.

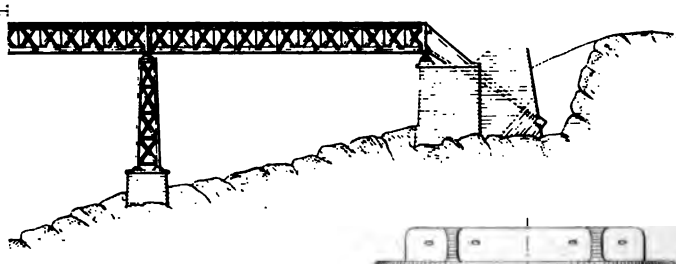


CROSS SECTION.

APPARATUS.

THOS. BELL & SON, LITH. GLASGOW & CURRENT, LONDON.

LISBON SIDE.



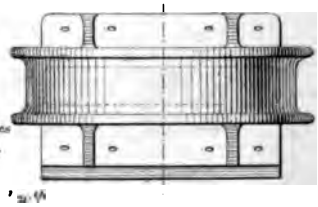
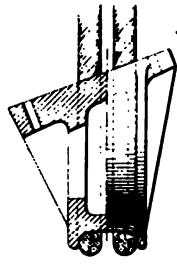
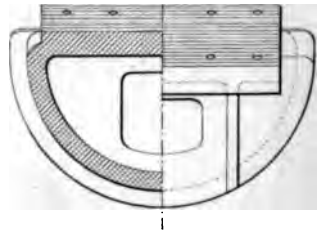


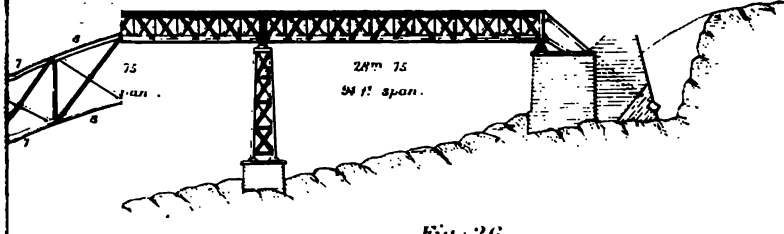
Fig : 25 .

Shoes under which pass the Ropes which supporting the beams of the Arches .

Scale 1/2th

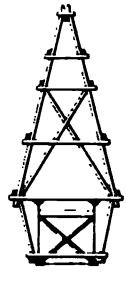






Left bank

Fig : 26 .

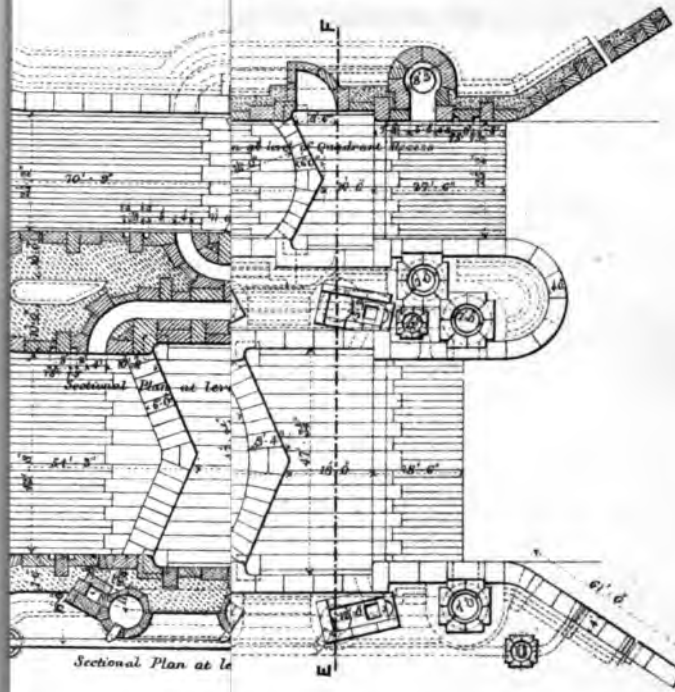


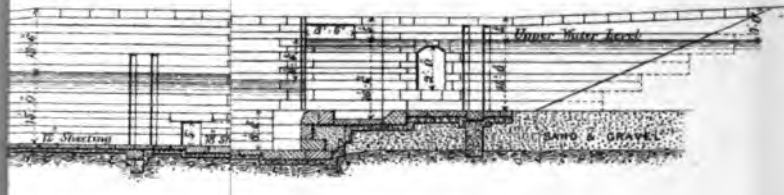
Scale 1/200th

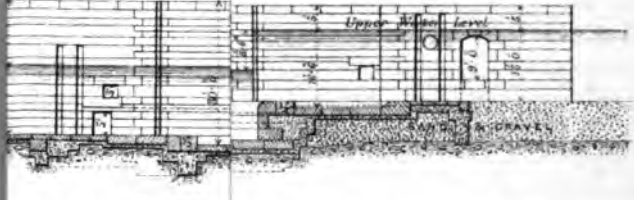
Cross Section of Trestle on Horizontal Girders .

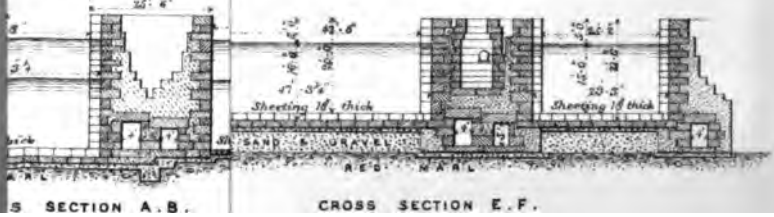
THE RIV

PLATE. II.





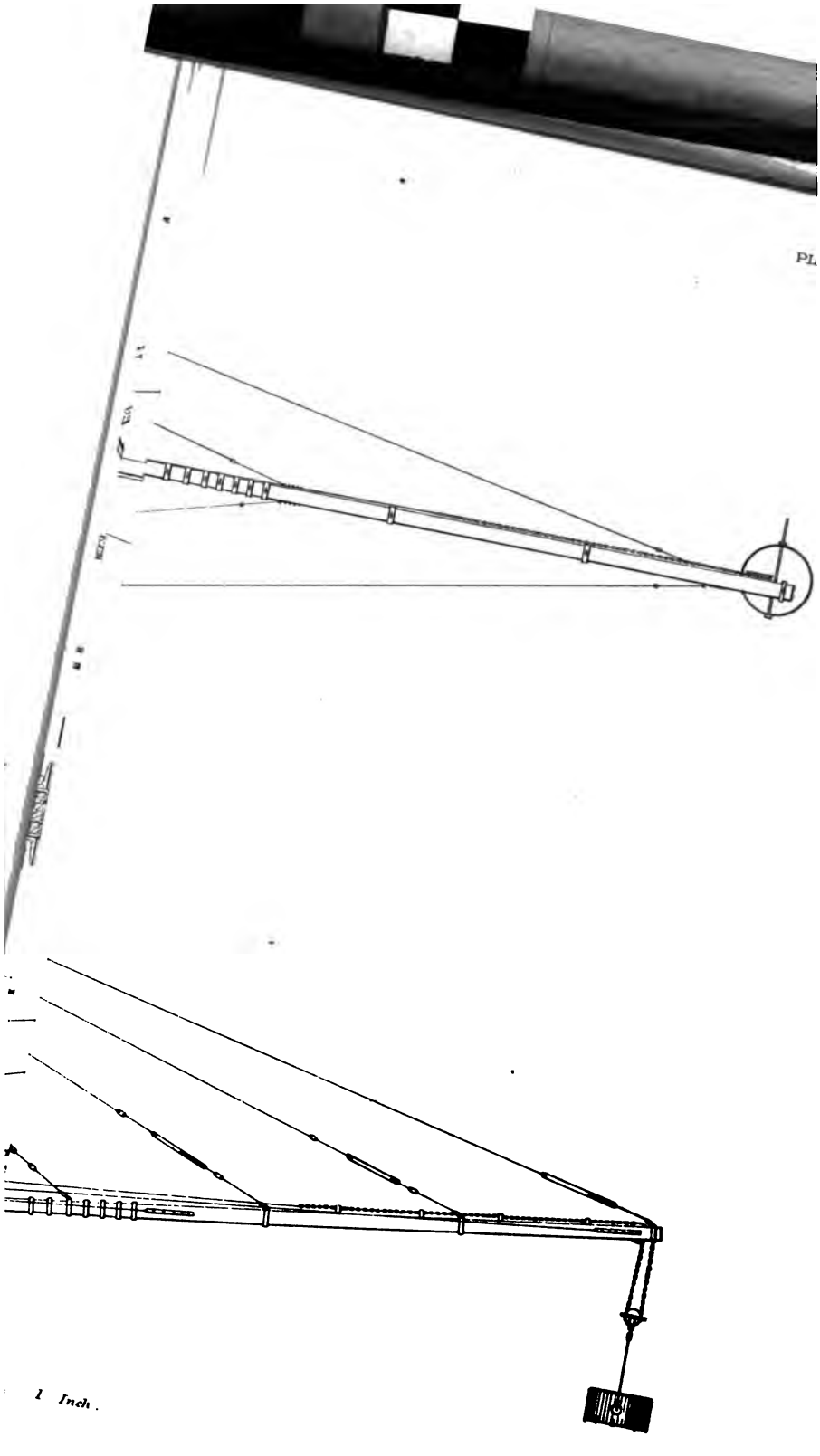




S SECTION A.B.

CROSS SECTION E.F.

THOS. KELLAW & SON 11TH AUGUST 1877 COVENT GARDEN

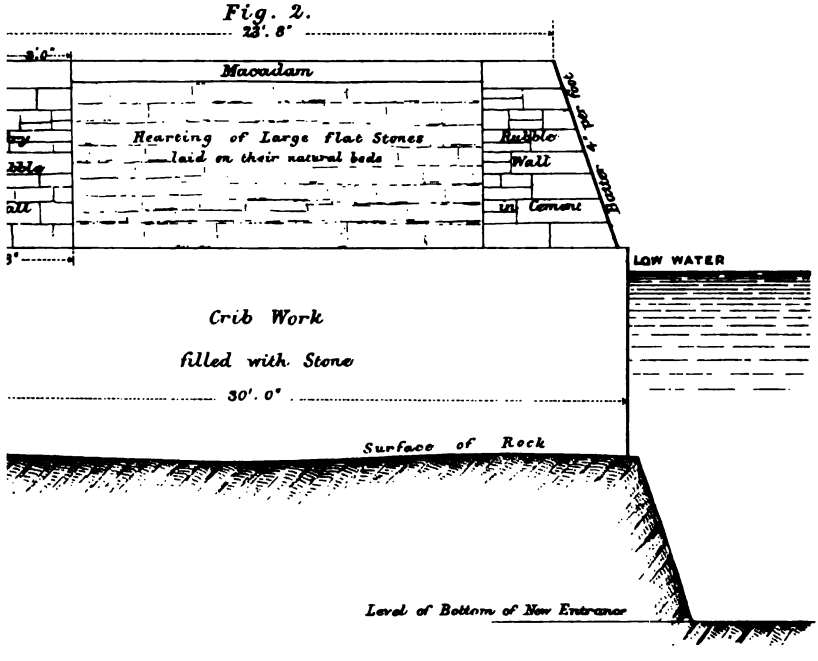


PL

1 Inch.

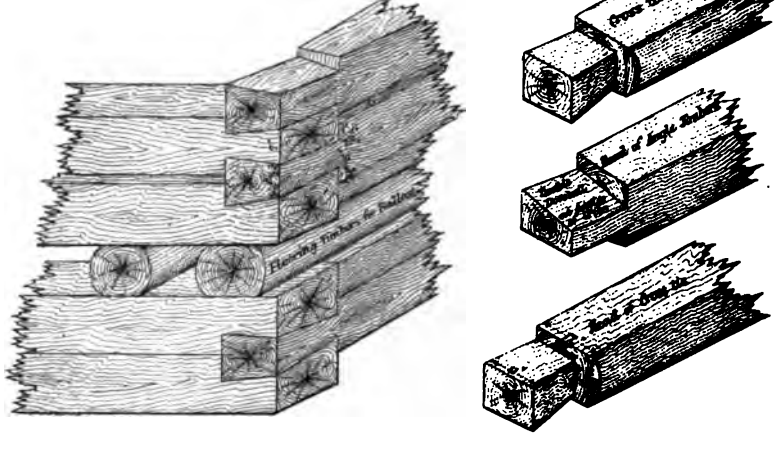
THOS. KELL & SON, LITH.

Fig. 2.



R AT LACHINE.

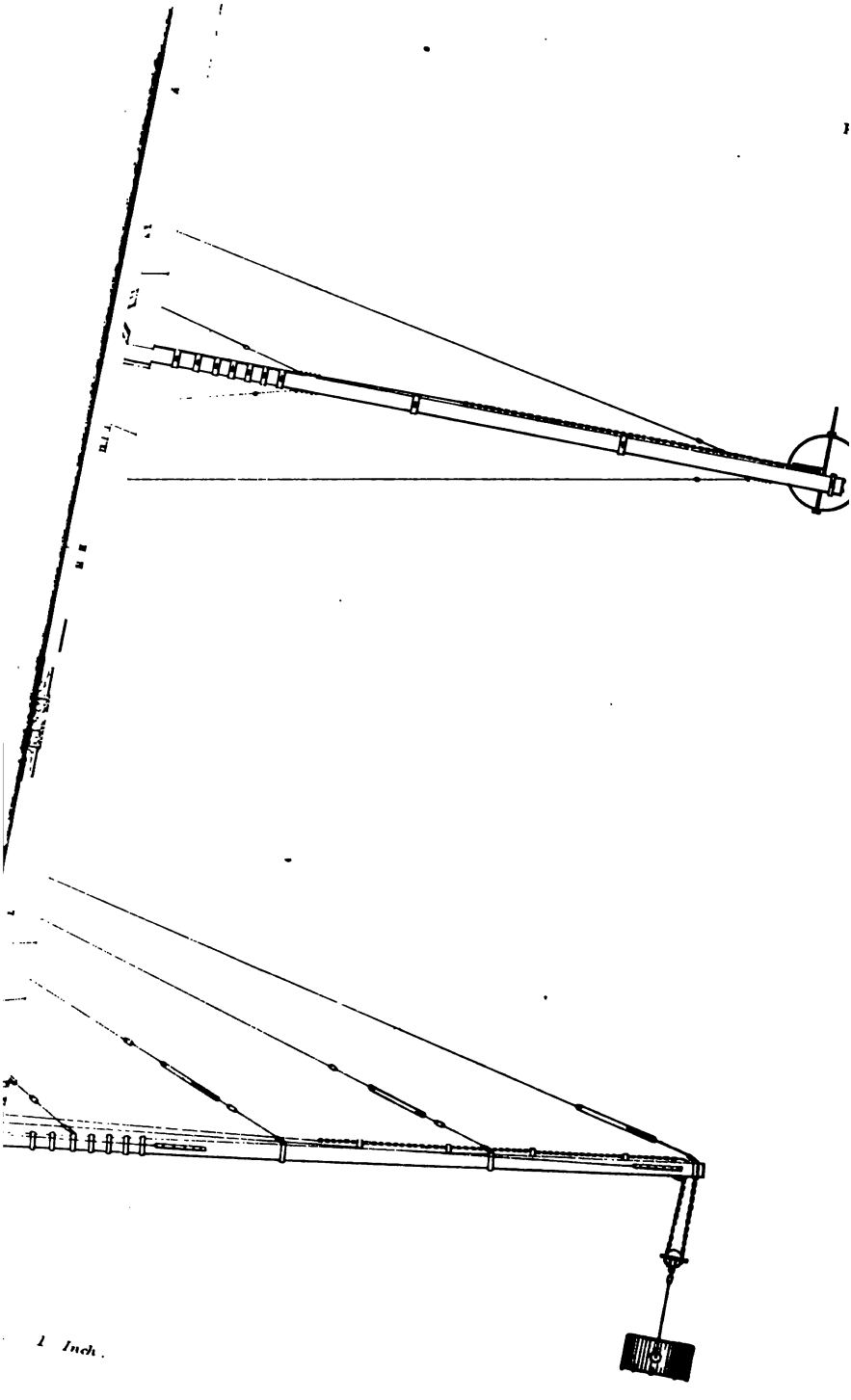
3.



VIEWS OF ANGLES OF CRIBWORK.

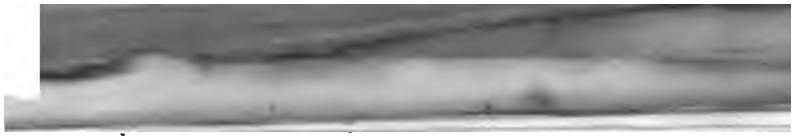
½ inch = 1 Foot.
= 1 Foot .

THOS. BELL & SON LITH. KING ST. COVENT GDN.



1 Inch.

THOS KELL & SON. LITH.



A

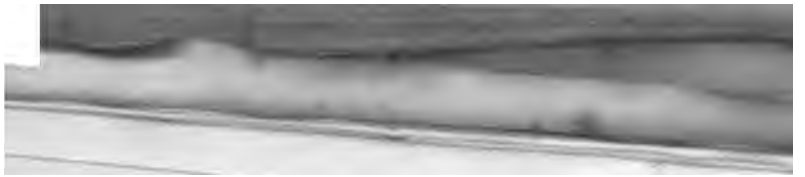


Fig: 2.

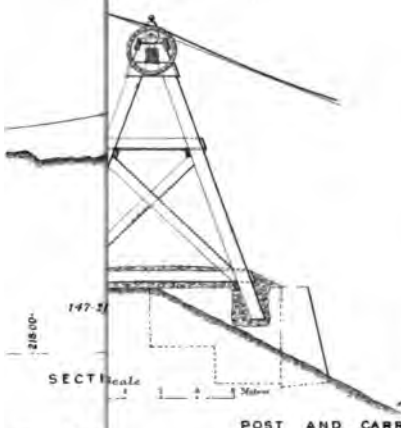
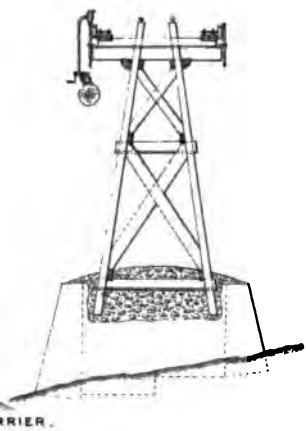
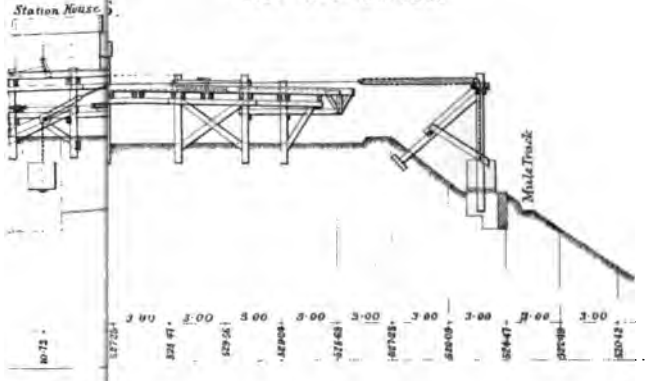


Fig: 3.



POST AND CARRIER.



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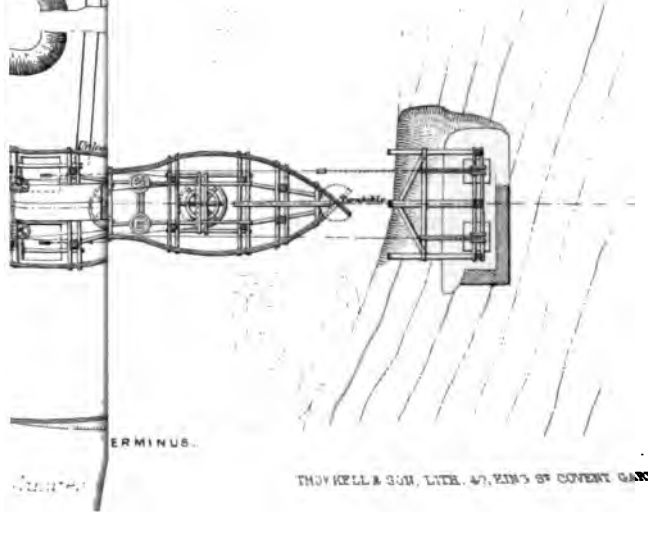

ERMINUS.

THOMAS KELL & SON, LITH. 47, KING'S ST. COVENT GARDEN.